Astronomy

THE WORLD'S BEST-SELLING ASTRONOMY MAGAZINE /// **DECEMBER 2025**

Planetary defenders

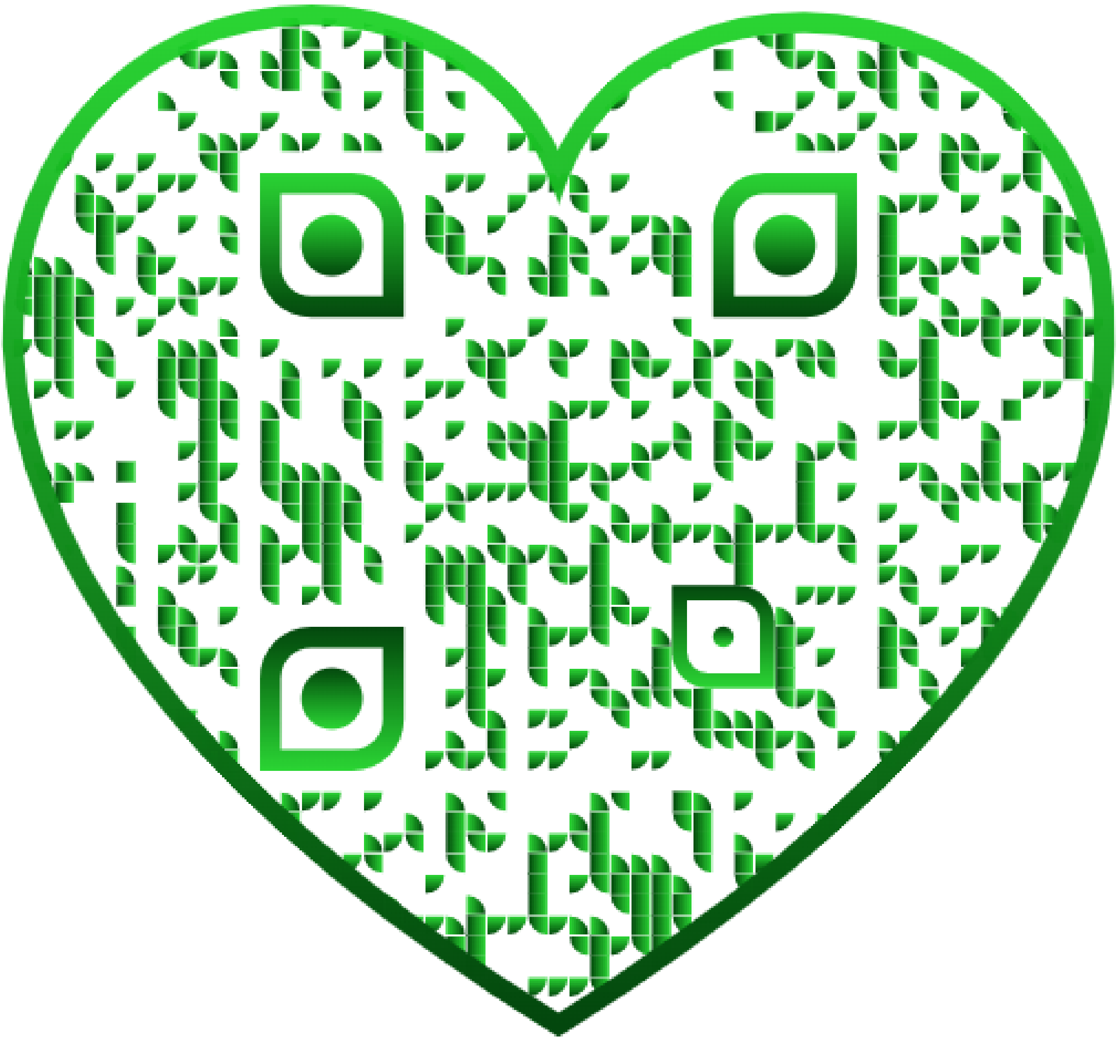
MEET THE GUARDIANS TRACKING KILLER ASTEROIDS

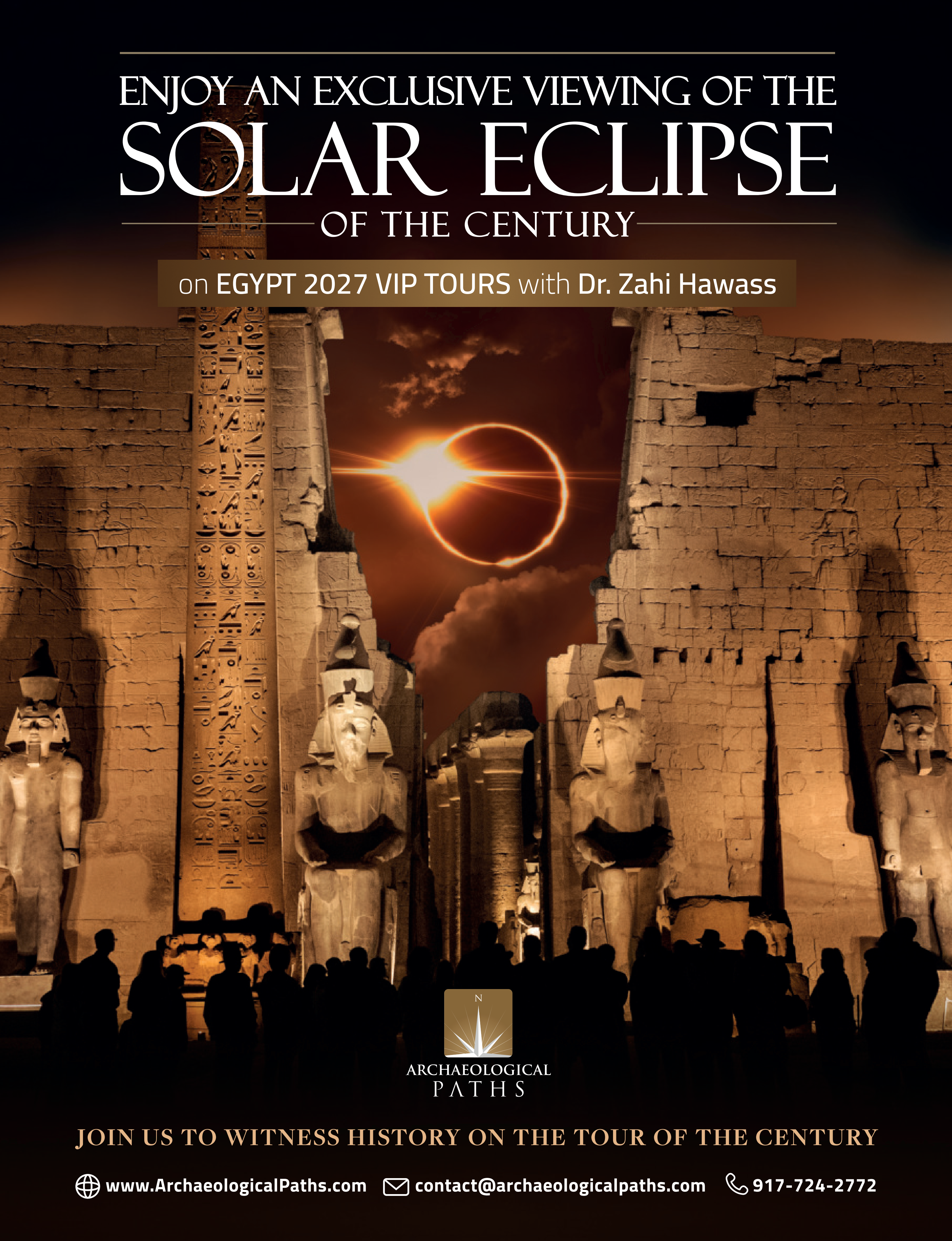
PLUS:

- SPOT AN ASTEROID TONIGHT
- DRONE SWARMS COULD ROAM MARS
- FAREWELL TO APOLLO 13'S JIM LOVELL
- BONUS: YOUR GUIDE TO 2026 SKY EVENTS

BONUS ONLINE CONTENT CODE p. 3

Vol. 53 • Issue 12





ENJOY AN EXCLUSIVE VIEWING OF THE
SOLAR ECLIPSE
OF THE CENTURY

on **EGYPT 2027 VIP TOURS** with **Dr. Zahi Hawass**

N
ARCHAEOLOGICAL
PATHS

JOIN US TO WITNESS HISTORY ON THE TOUR OF THE CENTURY

www.ArchaeologicalPaths.com contact@archaeologicalpaths.com 917-724-2772

CONTENTS
24

Online Content Code: ASY2512
Enter this code at **www.astronomy.com/code**
to gain access to web-exclusive content.

DECEMBER 2025
VOL. 53, NO. 12

ON THE COVER

The NEO Surveyor mission will be part of the planetary defense network of telescopes scanning the sky for potentially dangerous asteroids. *ASTRONOMY*: ROEN KELLY

FEATURES

12
How drones are redefining Mars exploration
The next leap toward humans on the Red Planet could be a swarm of rotorcraft, deployed in midair to chart the surface. **BROOKS MENDENHALL**

16 COVER STORY
How we track near-Earth asteroids
Meet the planetary defenders who are on the hunt for the next big asteroid that could impact Earth. **RANDALL HYMAN**

24
A farewell to Jim Lovell
Two Gemini and two Apollo flights cemented this trailblazing astronaut's place in history. **RICHARD TALCOTT**

28
Sky This Month
The Geminids put on a show. **MARTIN RATCLIFFE AND ALISTER LING**

30
Star Dome and Paths of the Planets
RICHARD TALCOTT; ILLUSTRATIONS BY ROEN KELLY

36
Spot an asteroid tonight
Seen the Messiers, Caldwells, and NGCs? There's another class of objects waiting. **GLENN CHAPLE**

40
Stars lost to history
There's a long list of celestial lights that have gone missing. **RAYMOND SHUBINSKI**

44
Astronomy tests ZWO's Seestar S30
With sharp optics, precise tracking, and a built-in filter set, this scope offers a great way to get into imaging. **PHIL HARRINGTON**

48
Ask Astro
Cosmic jets.

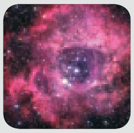
IN EVERY ISSUE

From the Editor **4**
Astro Letters **6**
Observing Basics **46**
MOLLY WAKELING
New Products **47**
Advertiser Index **47**
Reader Gallery **52**
Breakthrough **58**

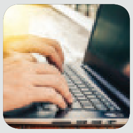
7
ASTRONEWS
Everything you need to know about the universe this month: JWST spots a nearby planet, a flawlessly spherical supernova shell puzzles astronomers, CPR in space gets a revamp, and more.

ONLINE FAVORITES

Go to **www.Astronomy.com** for info on the biggest news and observing events, stunning photos, informative videos, and more.


Picture of the Day
Gorgeous photos from our readers.

News
The latest updates from the science and the hobby.


Community forum
Enthusiasts connect and share.

The Space Store
Perfect gifts for your favorite science geeks.

Astronomy (ISSN 0091-6358, USPS 531-350) is published monthly by Firecrown Media Inc., 405 Cherry Street, Chattanooga, TN 37402. Periodicals postage paid at Chattanooga, TN and additional mailing offices. **POSTMASTER:** Send address changes to *Astronomy*, PO Box 850, Lincolnshire, IL 60069.

TOP: NASA (2). ONLINE FAVORITES, LEFT TO RIGHT: KPNO/NOIRLAB/NSF/AURA/N. A. SHARP; NASA/JPL/SPACE SCIENCE INSTITUTE; CHINGYUNSONG/DREAMSTIME.COM; *ASTRONOMY*: WILLIAM ZUBACK

New chapters

WILLIAM ZUBACK

To take on the role of editor-in-chief of *Astronomy* is a tremendously humbling honor. Like many of you, I grew up looking through an eyepiece and devouring anything written about the cosmos that I could get my hands on, including this magazine. I'm looking forward to working with our talented team to carry on the title's legacy and bring you the best magazine we can. We also plan to find new ways to serve and grow our community of observers, imagers, and all those fascinated by the universe and our place in it.

I am thrilled that Dave Eicher is staying on as editor emeritus. It's been a privilege to work with and learn from him over the past five years. After the magazine's founder, Steve Walther, nobody has done more for *Astronomy* than Dave. His voice will continue to appear in these pages for years to come.

I'd also like to welcome Staff Writer Brooks Mendenhall to the team. Brooks is a writer and editor based in Chattanooga, Tennessee. You've already read his news stories on Astronomy.com and in these pages. Now you'll be seeing his byline regularly on features, too.

We didn't plan this issue with a theme, but we could call it "The Asteroid Tracking Issue." In our cover story, Randall Hyman takes you behind the scenes of planetary defense — the researchers and telescope operators who find and track potentially dangerous asteroids. Then, on page 36, Glenn Chaple shows you how to observe these relics of the solar system through your own eyepiece.

In this issue you'll find Brooks' first feature for us, covering an innovative mission concept for deploying Ingenuity-like drones on Mars. It offers a glimpse into a possible future for space exploration, not only in its technology but also how it might be funded (or not).

And on page 24, Contributing Editor Rich Talcott has penned a remembrance of Jim Lovell. As a kid, I wore out my VHS tape of *Apollo 13* and my paperback copy of Lovell's memoir. In the coming years, astronauts from all over the world will set foot on the Moon. The heroics of Lovell and his crew are a reminder of their bravery — and what it means to have a home planet to return to.

Although these are uncertain times, one thing we can count on is that there will always be something new to discover whenever we look up. I can't wait to share that journey with you, our readers.

Mark Zastrow

Follow Mark on

Facebook:
facebook.com/mark.zastrow

X:
@markzastrow

Instagram:
@markzastrow

FOLLOW *ASTRONOMY*

facebook.com/AstronomyMagazine
twitter.com/AstronomyMag
youtube.com/user/AstronomyMagazine
instagram.com/astronomy.magazine

Astronomy

Editor-in-Chief Mark Zastrow
Assistant Design Director Kelly Katlaps

EDITORIAL
Senior Production Editor Elisa R. Neckar
Senior Editor Alison Klesman
Associate Editor Michael E. Bakich
Staff Writer Brooks Mendenhall
Editor Emeritus David J. Eicher

ART
Illustrator Roen Kelly
Production Director Kelly Kramer Weekley
Operations Specialist Melissa Valuch
Production Specialist Jodi Jeranek

CONTRIBUTING EDITORS
Bob Berman, Adam Block, Glenn F. Chaple Jr., Martin George, Tony Hallas, Phil Harrington, Korey Haynes, Alister Ling, Stephen James O'Meara, Martin Ratcliffe, Raymond Shubinski, Richard Talcott, Molly Wakeling

EDITORIAL ADVISORY BOARD
Buzz Aldrin, Marcia Bartusiak, Jim Bell, Timothy Ferris, Alex Filippenko, Adam Frank, John S. Gallagher III, Daniel W. E. Green, William K. Hartmann, Paul Hodge, Edward Kolb, Stephen P. Maran, Brian May, S. Alan Stern, James Trefil

Firecrown
Chief Executive Officer Craig Fuller
Chief Revenue Officer Jonathan Keller
Executive Vice President, Media Sales Preston Brown
Chief Operations Officer Nicole McGuire
Chief Financial Officer Tripp Thurston
Vice President, Finance/Controller Amanda Joyce
Vice President, Creative Barry Carpenter
Group President, Hobby Division Nicole McGuire
Group President, Aviation Division Kelly Keller
Group President, Marine Division David Carr
Editorial Director Kaylee Nix
Vice President, General Counsel Darren Caputo
Human Resources Director Suzie Matoh

ADVERTISING DEPARTMENT
Advertising Representative Kristi Rummel
Phone (608) 435-6220
Email kristi.rummel@firecrown.com

RETAIL TRADE ORDERS AND INQUIRIES
Selling *Astronomy* magazine or products in your store:
Email terri.meunier@firecrown.com

CUSTOMER SALES AND SERVICE
Phone (877) 246-4835
Outside U.S. and Canada (847) 313-3921
Customer Service AstronomyMagazine@Omeda.com

CONTACT US
Ad Sales adsales@astronomy.com
Ask Astro askastro@astronomy.com
Books books@astronomy.com
Letters astronomyeditorial@astronomy.com
Products products@astronomy.com
Reader Gallery readergallery@astronomy.com

For reprints, licensing, and permissions:
PARS International at www.parsintl.com

Copyright © 2025 Firecrown Media Inc., all rights reserved. This publication may not be reproduced in any form without permission. Printed in the U.S.A. Allow 6 to 8 weeks for new subscriptions and address changes. Single copy: $6.99 (U.S.). Print + digital subscription rate: U.S.: 1 year $58.95. Canadian: Add $12.00 postage. Canadian price includes GST, payable in U.S. funds. All other international: Add $22.00 postage, payable in U.S. funds, drawn on a U.S. bank. BN 12271 3209 RT. Not responsible for unsolicited materials.

FIRECROWN

Please Recycle This Magazine

FOR SALE:

Welcome to Sunshine Wells, a stunning 337-acre guest ranch situated in the dark countryside of Luna County, NM, just 15 miles from the nearest town. This unique ranch offers both solitude and convenience, with easy access, only 20 minutes to I-10, and just 1.5 hours to the El Paso airport. The spacious ranch house features 5 to 8 bedrooms and over 8,000 square feet of fully furnished living space. Enjoy an onsite observatory with four telescopes, a swimming pool, spa, and sustainable solar power. Experience amazing 100-mile views from every direction.

Connor Murray | m: 603.918.1745 | o: 575.532.5678 | EXIT Realty Horizons

Astronomy 2025 Star Products

StellarMate

COMPACT ASTROPHOTOGRAPHY CONTROLLER

COMPATIBLE WITH COUNTLESS DEVICES

www.stellarmate.com

CONTROL FROM MOBILE, WEB, OR DESKTOP PLATFORMS

Mounts, Cameras, Focusers, Filter Wheels, Domes, and complete observatories.

SNOW KING

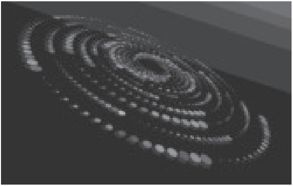
OBSERVATORY & PLANETARIUM

Jackson, Wyoming - www.skobservatory.com

Explains the **BIG BANG**

ON THE NATURE OF SPACE, TIME, AND, EVOLUTION

2nd Edition Revised

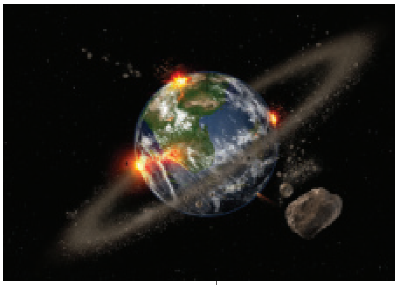

Jan F. Andrus

Former Space Scientist

www.janfandrus.com

Available on Amazon

ASTRO LETTERS



Around 460 million years ago or so, Earth may have sported a ring — debris from which eventually pelted our planet's surface.
ASTRONOMY: ROEN KELLY

We welcome your comments via email to **astronomyeditorial@astronomy.com**. *Please include your name, city, state, and country. Letters may be edited for space and clarity.*

How fast is fast?

On page 9 of the August issue, "A Local 'Dark Galaxy'" speaks of a galaxy that's part of a high-velocity cloud, and indicates those clumps of hydrogen are moving several hundred mph faster than gas in the Milky Way's plane. Several hundred mph faster doesn't seem to qualify as high-speed when referring to motion in the galaxy. Should that have been several hundred miles per *second* faster? **— John A. Ferko,** Fort Belvoir, VA

Senior Editor Alison Klesman responds: *According to the* Science Advances *study referenced in the story, "High-velocity clouds (HVCs) are defined by their line-of-sight velocities exceeding 90 kilometers per second relative to the local standard of rest (LSR)."*

Line-of-sight velocity is the cloud's speed directly toward or away from us, not including any "sideways" motion on the sky. The LSR is a frame of reference that follows the general motion of the galaxy in the vicinity of the Sun. The Sun orbits the galactic center at about 230 kilometers per second (143 miles per second).

A speed of 90 kilometers per second is about 56 miles per second, or a little over 200,000 mph. So yes, we did understate the speed of HVCs in miles per hour. But note that they do not need to be moving several hundred miles per second faster than their surroundings to be considered HVCs — only 56 miles per second or so.

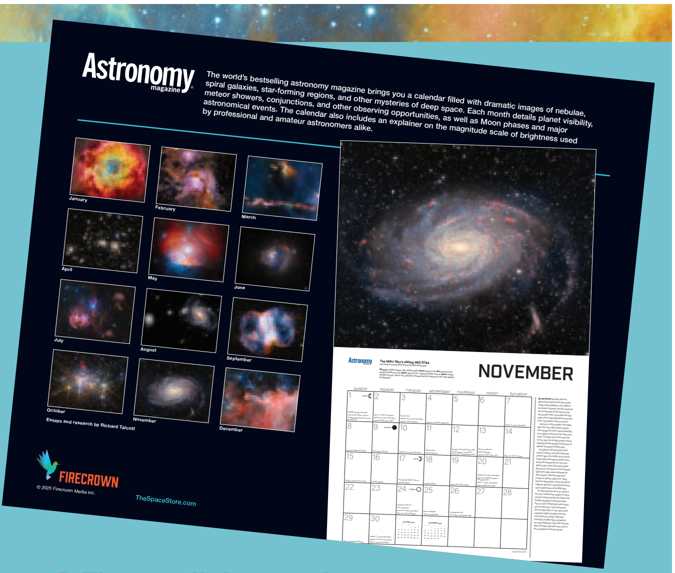
Ring theory

I've been a reader of *Astronomy* for many years. I really enjoy getting my issue each month. Your recent article "Did Earth once have a ring?" (August 2025) made me think of another possibility. If the Moon formed, as theorized, by the impact of a Mars-sized object, it seems not beyond reason that material in orbit while the Moon was coalescing would have formed a ring around our planet.
— Tim Holmes

Erratum

The item "Round and round" on page 9 of our August 2025 issue misstated the timescale for a new cosmological hypothesis. In it, the universe may be rotating once every half-trillion years, not every half-billion.

2026
DEEP SPACE MYSTERIES
CALENDAR
Astronomy



ASTRONOMY'S
DEEP SPACE MYSTERIES
2026 CALENDAR

➔ **The world's best-selling astronomy magazine** brings you an exclusive calendar filled with stunning images, detailed observing opportunities, as well as major astronomical events. Each month details planet visibility, meteor showers, conjunctions, and much more!

Shop Now at TheSpaceStore.com/CAL26

the space store

SNAPSHOT

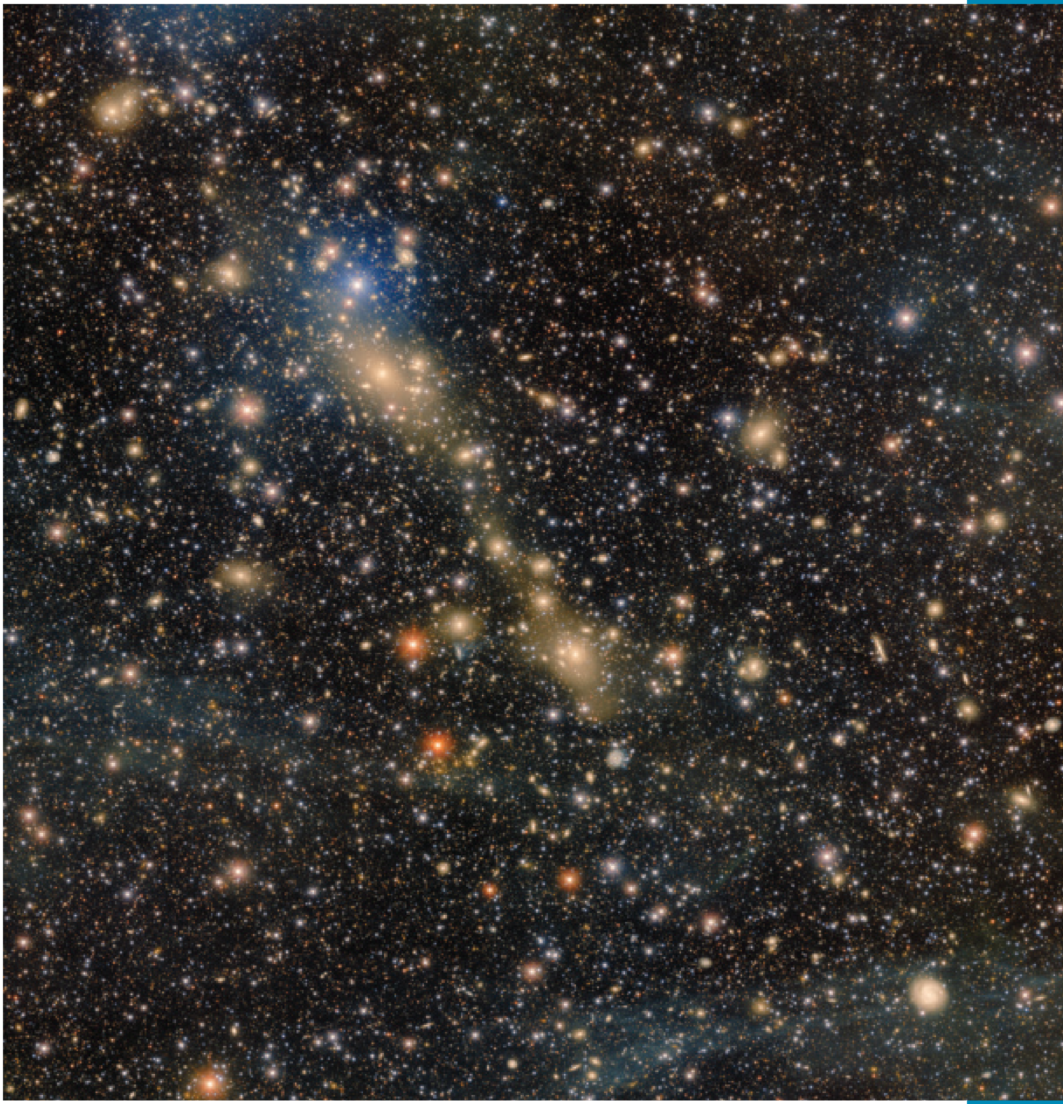
A BRIDGE OF STARS

The deepest image ever taken of Abell 3667 illuminates the cluster's history.

This galaxy-studded view represents the deepest image ever of Abell 3667, a rich cluster of galaxies some 700 million light-years away. The composite image comprises 28 total hours of observations taken over the course of about a decade with the 570-megapixel Dark Energy Camera on the Víctor M. Blanco 4-meter Telescope in Chile.

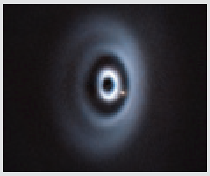
Just left of center is a glowing bridge of yellow starlight connecting Abell 3667's two brightest galaxies, each of which represents the center of a smaller galaxy cluster. These two clusters are coming together to create one larger cluster. The so-called intracluster light is generated by stars stripped from the smaller of these two bright galaxies by its larger counterpart as they merge. Spanning about a million light-years, it is the largest such structure ever seen in the local universe.

Also visible are wispy blue "clouds" that look like drifting smoke. Sometimes called galactic cirrus, these are foreground clouds of dust in our own Milky Way that are lit by the soft glow of the many stars in our galaxy combined. – ALISON KLESMAN



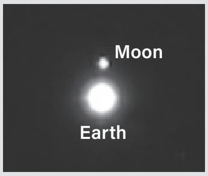
CTIO/NOIRLAB/NSF/AURA. ACKNOWLEDGMENT: PI: ANTHONY ENGLERT (BROWN UNIVERSITY). IMAGE PROCESSING: T.A. RECTOR (UNIVERSITY OF ALASKA ANCHORAGE/NSF NOIRLAB), M. ZAMANI & D. DE MARTIN (NSF NOIRLAB).
BOTTOM FROM LEFT: ESO/R. F. VAN CAPELLEVEEN ET AL; NASA/JPL-CALTECH/ASU; NASA, ESA, CSA, STSCI, M. EL MOUTAMID (SWRI), M. HEDMAN (UNIVERSITY OF IDAHO)

HOT BYTES



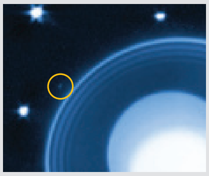
DUST BUSTER

Astronomers imaging the young Sun-like star WISPIT 2 spotted a 5-Jupiter-mass gas giant carving a clear path in the disk of dust and gas around its sun. It's only the second planet seen at such an early age around a star like our own.



TEST SHOT

On July 20, NASA's Psyche imaged Earth and the Moon from a distance of 180 million miles (290 million km). These engineering shots indicate how the cameras respond to reflected sunlight, which is how they will study the asteroid Psyche upon arrival in 2029.

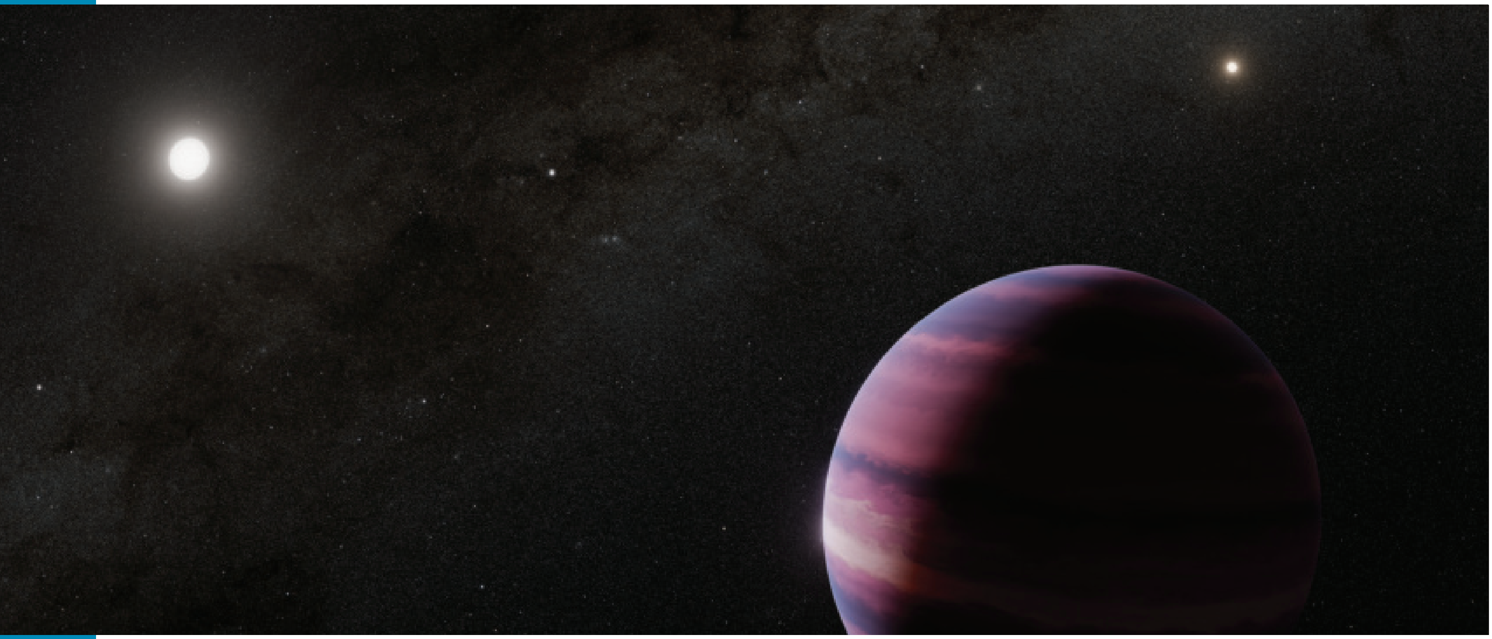


NEW MOON

In February, JWST discovered a new moon orbiting Uranus, designated S/2025 U$_1$. Just 6 miles (10 km) across, it is smaller and fainter than any of the planet's other moons — and was impossible for Voyager 2 to spot.

JWST DISCOVERS POSSIBLE PLANET AROUND ALPHA CENTAURI A

The Sun's closest neighbors have proved difficult for planet hunters, but the infrared scope may have uncovered a Saturn-mass world.



POSSIBLE PLANET. The Saturn-mass gas giant planet potentially orbiting Alpha Centauri A appears in the foreground of this artist's concept. Its star, Alpha Centauri A, is at upper left, while Alpha Centauri B is shown at upper right. NASA, ESA, CSA, STSCI, ROBERT HURT (CALTECH/IPAC)

» Astronomers using the James Webb Space Telescope (JWST) have imaged a potential gas giant planet orbiting Alpha (α) Centauri A, a Sun-like star in the closest stellar system to our own. The discovery was published Aug. 11 in two papers in *The Astrophysical Journal Letters*.

The Alpha Centauri system consists of Alpha Centauri A and B, two Sun-like stars that form a tight binary pair, along with the more distant and fainter red dwarf Proxima Centauri, which orbits them both. They are about 4.3 light-years from Earth.

While Proxima Centauri is known to host at least two planets, Alpha Centauri A and B have proven far more elusive targets for planet hunters. The main obstacle is their intense, overlapping glare. Even when the light from one star is physically masked using an instrument called a coronagraph, the brilliance of the other obscures the faint reflected light of any planets.

The team used the coronagraph within JWST's Mid-Infrared Instrument (MIRI) to make the "incredibly challenging" observations in August 2024, said Charles Beichman of NASA's Jet Propulsion Laboratory, one study's first author, in a press release. "Because these stars are bright, close, and move across the sky quickly," he explained, the telescope's operators "had to come up with a custom observing sequence just for this target, and their extra effort paid off spectacularly."

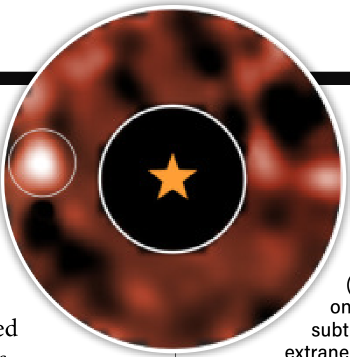
To deal with the glare that had stymied previous efforts, the team modeled how light from Alpha Centauri A and B scatters around the mask and within the telescope's optics. By subtracting this model from the original image, they revealed a faint dot of light that might be a planet, now called S1.

DISAPPEARING PLANET

The story took a mysterious turn when follow-up observations in February and April 2025 failed to spot the object. "We are faced with the case of a disappearing planet!" said Aniket Sanghi, a Ph.D. student at Caltech and first author of the other paper. To determine why, the team simulated millions of possible orbits to determine the planet's position around the star at different times. The models revealed that 52 percent of stable orbits were consistent with a planetary position in early 2025 that rendered it invisible to the telescope, potentially explaining why it wasn't seen.

The team emphasized in their

conclusions that with only a single sighting, S1 cannot yet be "unambiguously confirmed as a bona fide planet." Nonetheless, based on the initial observations and orbital models, a picture of the potential new world has started to form. It is likely a gas giant with a mass similar to Saturn, on an elliptical orbit around Alpha Centauri A that varies between one and two times the distance of Earth from the Sun. Although it lies within the star's habitable zone, where liquid surface water is possible, as a gas giant it could not support life as we know it.



CLEARING THE VIEW. JWST obtained this view of the planet candidate S1 (circled) around Alpha Centauri A (marked by a star) by using an onboard coronograph and subtracting a model of the extraneous starlight. NASA, ESA, CSA, ANIKET SANGHI (CALTECH), CHARLES BEICHMAN (NEXSCI, NASA/JPL-CALTECH), DIMITRI MAWET (CALTECH); IMAGE PROCESSING: JOSEPH DEPASQUALE (STSCI)

If confirmed, Sanghi said the discovery "would mark a new milestone for exoplanet imaging efforts." He added, "[The planet's] very existence in a system of two closely separated stars would challenge our understanding of how planets form, survive, and evolve in chaotic environments."

—BROOKS MENDENHALL

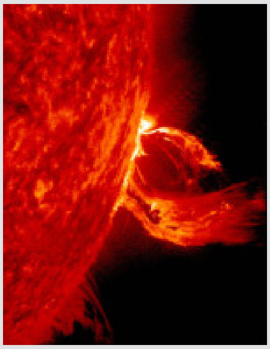
Carbon emissions are a drag on satellites

RISING CARBON DIOXIDE (CO_2) levels aren't just affecting climate on Earth — they could also change the way our upper atmosphere responds to geomagnetic storms. This change could impact orbiting craft and services like GPS and satellite internet.

Research published June 14 in *Geophysical Research Letters* modeled the response of the upper atmosphere to the same fierce solar storm in three future years — 2040, 2061, and 2084 — as levels of CO_2 rose according to current high-emissions scenarios. The study focused on the thermosphere, which extends from about 50 to 440 miles (80 to 700 kilometers) above the planet. Although increasing CO_2 near the surface causes temperatures to warm, it has a cooling effect on the thermosphere, causing this region to contract and leading to lower density over time.

The team found that as CO_2 increases, the thermosphere's density will drop by 20 to 50 percent by 2084. But they also found that its response to solar storms increased. A strong storm today might double the thermosphere's density; in the future a similar storm could nearly triple its density, albeit from a lower starting point.

Any increase in the thermosphere's density increases the drag felt by satellites in low Earth orbit, putting them at risk for premature reentry or collisions caused by widespread automatic boosts to stay in orbit. Larger changes in thermosphere density due to geomagnetic storms will create a more volatile environment where atmospheric drag can change rapidly and dramatically, according to lead author Nicolas Pedatella of the National Center for Atmospheric Research in Boulder, Colorado. "For the satellite industry, this is an especially important question because of the need to design satellites for specific atmospheric conditions," Pedatella said in a press release.



SOLAR STORM. A huge wave of plasma, called a coronal mass ejection, erupts from the Sun in June 2015. Such events can trigger geomagnetic storms on Earth when they reach our planet. NASA/SDO

While these predictions are a major step forward, the team notes there are still complexities to explore. Regardless, the study makes one thing clear: As we continue to alter the composition of our atmosphere, we are also changing its relationship with the Sun. —B.M.

QUICK TAKES

IDENTITY UNKNOWN

Earendel, hailed in 2022 as the most distant single star ever discovered (28 billion light-years away), may actually be a tightly packed star cluster, according to new modeling of data taken by JWST.

REACTOR RUSH

In August, NASA declared its intent to place a nuclear reactor on the Moon by 2030, aiming to preempt similar plans from China and Russia. The agency solicited proposals from industry for a fission power system producing at least 100,000 watts of power.

STRIKE THREE

The Earth-sized exoplanet TRAPPIST-1 d, which lies on the edge of its star's habitable zone, does not have a thick atmosphere, JWST transmission spectroscopy has found. That's the third planet in the system, after b and c, where JWST has not seen evidence of a significant atmosphere.

BOUNCING BACK

SpaceX's Starship met all major mission objectives on its 10th test flight Aug. 26 following three successive failures and a test stand explosion earlier this year. After launching from Texas, the Starship upper stage splashed down in the Indian Ocean, collecting valuable engineering data.

SPACE DEREGULATION

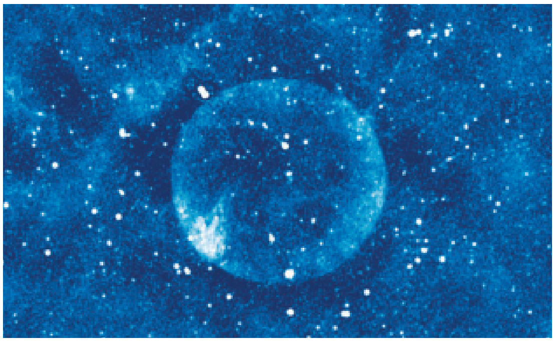
In a bid to jump-start competition in the U.S. space sector, President Donald Trump issued an executive order Aug. 13 directing federal agencies to relax requirements for commercial launch and reentry licenses, including environmental regulations on spaceports.

EAVESDROPPING ON E.T.

If alien civilizations explore their solar systems like we do, SETI researchers should target exoplanet alignments where their signals to spacecraft might spill over to us, researchers suggest after studying 20 years of NASA transmissions.

— MARK ZASTROW, JACK DALEO

A perfectly spherical supernova remnant



FILIPOVIĆ ET AL. HTTPS://DOI.ORG/10.48550/ARXIV.2505.04041

Astronomers are puzzling over a newfound object that seems to defy cosmic chaos: a glowing, nearly flawless circular shell of gas and dust that has remarkably preserved its shape. Miroslav Filipović of Western Sydney University spotted the remnant using the Australian Square Kilometre Array Pathfinder radio telescope and named it Teleios — Greek for "perfect." (Its formal name is SNR G305.4-2.2.) The supernova remnant spans between 45 and 150 light-years, lies between 7,000 and 25,000 light-years away, and displays exceptional symmetry. Its near-perfect shape may be due to its location away from the crowded galactic plane, where fewer obstacles allowed its shock wave to expand almost untouched in this cleaner environment. –SHARMILA KUTHUNUR

BOTS BEST AT SPACE CPR

STAYIN' ALIVE. Andreas Mogensen of the European Space Agency practices the handstand technique for CPR aboard the International Space Station in a regularly scheduled training session. NASA

ASTRONAUTS MIGHT BE BETTER OFF with robot medics — at least when it comes to CPR.

French researchers simulating weightlessness on zero-gravity jet flights have found that manual cardiopulmonary resuscitation (CPR) is not effective in space, which could reshape emergency medical protocols for upcoming missions to the Moon and Mars.

In weightlessness, simply pushing on a patient's chest would send both rescuer and patient floating apart. So for decades, astronauts have been trained in a "handstand" technique where rescuers brace their feet against spacecraft walls. But in tests on training mannequins aboard parabolic flights, humans could achieve only 1.36 inches (34.5 millimeters) of compression depth, well below the suggested 1.97 to 2.36 inches (50 to 60 mm).

On the other hand, Automatic Chest Compression Devices (ACCDs) consistently achieved the required compression depth. These machines strap around the patient's torso and create a self-contained system that generates both compression force and counter-force.

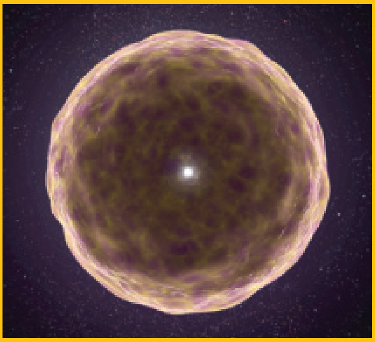
ACCDs could also prove useful on the Moon and Mars, where reduced gravity means astronauts may have insufficient weight for effective CPR, the French team says. –B.M.

STAR'S GUTS LAID BARE BY SUPERNOVA

We are made of star-stuff, as Carl Sagan liked to say. Physics tells us that most of the heavier elements in our bodies and the environment around us were forged within massive stars and scattered in their explosive deaths.

But astronomers hadn't directly observed this process until they came across the supernova SN2021yfj, discovered in September 2021 by the Zwicky Transient Facility in California. Most supernovae show strong signatures of only hydrogen and helium, which make up most stars' outer layers. But follow-up study by the Keck Observatory in Hawaii revealed that SN2021yfj was rich in elements like silicon, sulfur, and argon — all formed in the star's deeper layers in the final stages of its life. The work was published Aug. 20 in *Nature*.

That this material was exposed means the star was missing its outer layers, which astronomers are struggling to explain. The team's current thinking is that the star's extreme temperatures late in life caused light to spontaneously convert into matter, destabilizing the star and ejecting its outer material in a series of pulsations. Astronomers have seen supernovae that seem triggered by this mechanism before, but none as revealing as this one. –M.Z.



POST-MORTEM. The star that exploded as SN 2021yfj spewed silicon (shown as gray), sulfur (yellow), and argon (purple) into space, depicted in this illustration. W.M. KECK OBSERVATORY/ADAM MAKARENKO

Because telescopes are for one-eyed pirates

BT 127 SD

Reviewed:

OBERWERK
Obsessed with Binoculars®
oberwerk.com

CHROMA
Astronomy Filters
chroma.com/astronomy

From faint galaxies to bright nebulae, Chroma's precision filters capture it all—pure, accurate, breathtaking.

— Image taken by Tony Hallas

Give The Gift of *Astronomy* magazine and SAVE!

Gift Recipient Receives:

- **Star Maps & Guides:** Monthly maps and tips for optimal stargazing
- **Gear Reviews:** Unbiased advice on telescopes and astronomy equipment.
- **Special Editions:** Access to exclusive issues and in-depths supplements
- **Digital Access:** Read on any device, anytime
- **So Much MORE:** Gift today and explore!

Astronomy.com/Subscribe

ScopeBuggy

- For use with most tripods, DOBs and piers
- 10" Pneumatic tires for soft ride
- Load tested to 600+ pounds
- Assemble & disassemble in minutes
- Adjustable rear axle height (1½" to 7")
- Ideal for scopes up to 36"
- One person can quickly and easily move any sized scope

STILL #1

$345.00*
Plus S&H
Approx. $70 Shipping
USA
*Subject to change

Patent Pending

SCOPEBUGGY
P.O. BOX 834
Elephant Butte, NM
87935

915-443-9010

www.ScopeBuggy.com

ToupTek Astro

Telescope: ToupTek Astro HOPE D60
Main Camera: ToupTek Astro SkyEye62AC
Guide Camera: ToupTek Astro G3M678C
Equatorial Mount: iOptron CEM70

HOPE Series Telescope

PAPO Precision ,
Near-Zero Chromatic Smear

Built-in Flattener ,
Diffraction-Limited Clarity

HOPE PAPO D60 280mm f/4.66L

Aperture: 60mm | Focal length: 280mm | Focal ratio: f/4.66

1.Optical System: 5-element APO design (SD & lanthanum glass), exceptional sharpness, near-theoretical Strehl ratio.
2. Built-in Field Flattener: 50-58mm connection distance (55mm recommended) for simplified focusing.
3. Retractable Lens Hood: Reduces stray light, improves contrast & clarity.
4. Focuser: 3" dual-speed rack-and-pinion for smooth, precise adjustments.
5. Multi-functional interfaces: M48/M54 threads, high compatibility for diverse imaging needs.
6. High-strength lens barrel structure: CNC-machined aluminum alloy, high precision & stability for tough environments.

Facebook@ToupTek Astronomy Cameras
Instagram@touptekastro
YouTube@ToupTek Astro

E-mail: astro@touptek.com
Learn more at www.touptek-astro.com

Fundamentals First Fund

An ETF
Symbol KNOW
Your money
Carefully managed

FIRST CLASS WORK

Abstract

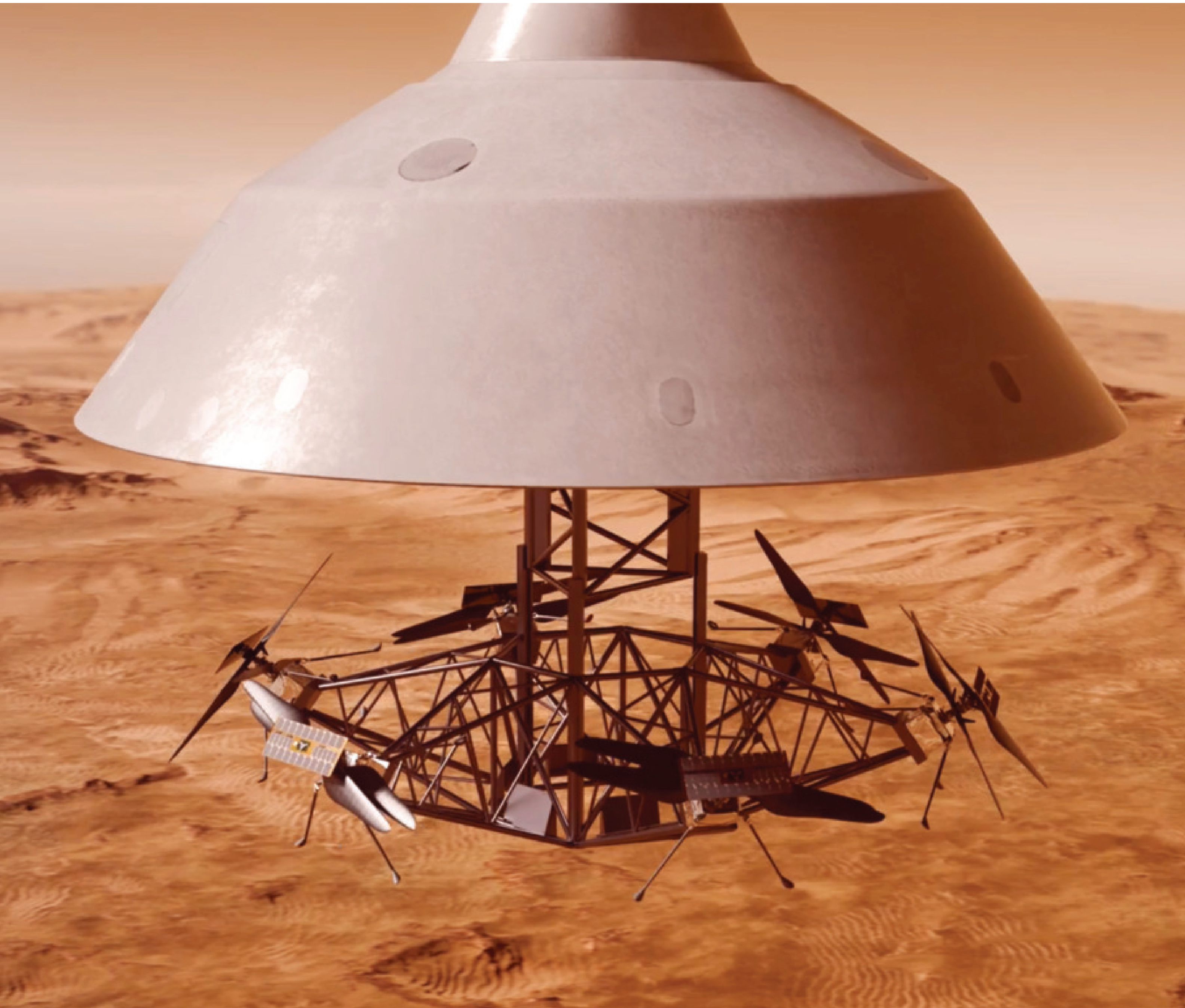
The Fundamentals First Fund, an ETF, is part owner of approximately 100 publicly traded worthy companies, and it owns publicly traded debt. These worldwide companies are vital, important, useful, or just plain nice to have around, and most have been pursuing their business course for decades. We individually select these companies with care and in a manner as to spread our risk so that no single company event can cause more than a bruise. Mason Capital has managed money this way for more than three decades. If you are more specifically interested in who we are, how we do it, and how you might participate, read on.

www.FundamentalsFirstFund.com
(Our Website Has a Lot About Us)

2/21/24 IPO Market Open: $10.00
7/31/25 Market Close: $11.29
Dividends Paid: $ 0.24

Investors should consider the investment objectives, risks, charges and expenses carefully before investing. For a prospectus or summary prospectus with this and other information about the Fund, please call 617-228-5190 or visit our website at www.fundamentalsfirstfund.com
Investments involve risk. Principal loss is possible.
Quasar Distributors LLC.

HOW DRONES ARE REDEFINING MARS EXPLORATION



The next leap toward humans on the Red Planet could be a swarm of rotorcraft, deployed in midair to chart the surface.

BY BROOKS MENDENHALL

IN A BOLD NEW PROPOSAL for exploring Mars, aerospace firm AeroVironment has unveiled Skyfall, a potential mission concept that would ditch the traditional lander and rover in favor of a swarm of six autonomous helicopter drones.

The proposed mission, announced July 24, would leverage the agility of autonomous rotorcraft like NASA's Ingenuity, which operated on Mars from 2021 to 2024. If it becomes reality, a Skyfall mission could reveal prime locations for future human missions and scientific investigations.

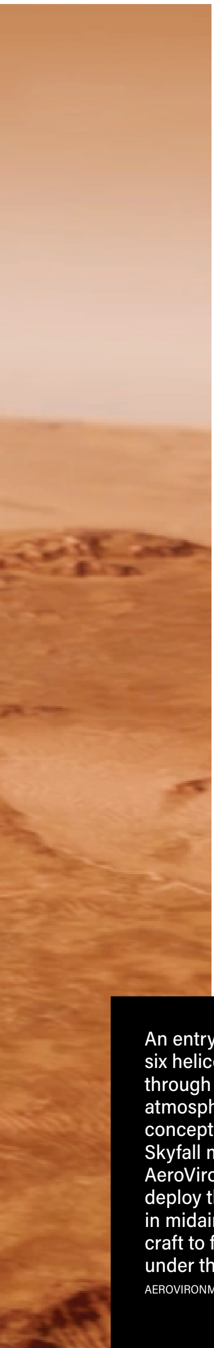
AeroVironment sees Ingenuity-like drones as ideal reconnaissance scouts, filling a gap between the global coverage of orbiters and the limited mobility of landers and rovers. The record for the longest distance covered by a rover, set by NASA's Opportunity, is just over the length of a marathon, notes William Pomerantz, AeroVironment's head of space ventures. "It's sort of like if somebody came to planet Earth and saw downtown Chattanooga and said, 'Well, I guess that's it. I've seen the whole planet.'"

Drones are the "mobility champion of Mars," says Pomerantz, able to survey martian terrain in greater detail than orbiters and travel faster and farther than rovers — as well as traverse treacherous terrain that could prove impossible for a ground-based vehicle.

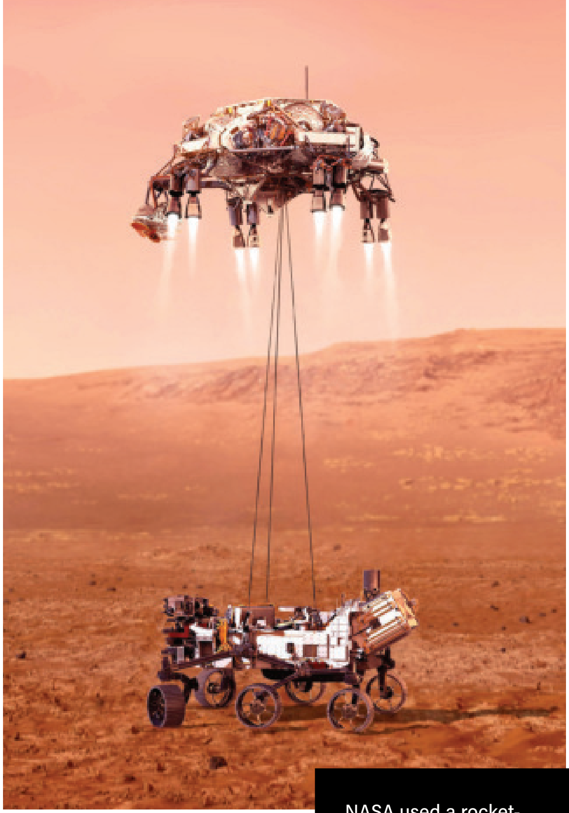
A radical new landing

The mission's centerpiece is what its developers call the "Skyfall maneuver." For decades, NASA has relied on complex entry, descent, and landing (EDL) systems. The multibillion-dollar Curiosity and Perseverance rovers, for instance, underwent completely autonomous EDLs with parachutes and a rocket-powered sky crane that winched the massive vehicles down on cables — a procedure famously called the "seven minutes of terror."

Skyfall offers a simpler solution. Instead of a single, precious lander, an entry capsule would release the six helicopters during its descent through the thin martian atmosphere. The rotorcraft would then break away and fly themselves down to the surface under their own power, eliminating the need for an expensive and risky landing platform.



An entry vehicle carrying six helicopters descends through the martian atmosphere in this artist's concept. The proposed Skyfall mission by AeroVironment would deploy the drone swarm in midair, allowing the craft to fly to the surface under their own power. AEROVIRONMENT



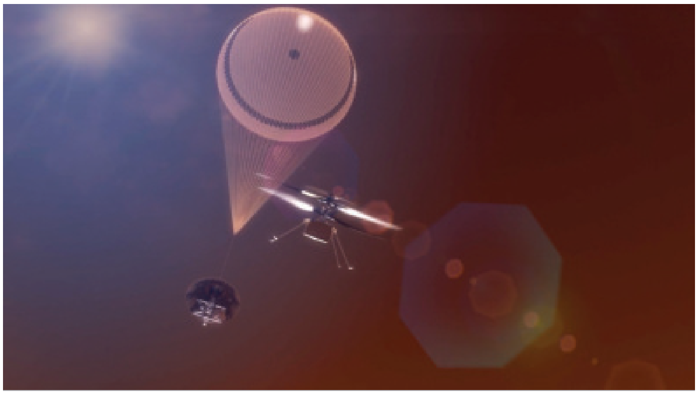
NASA used a rocket-powered sky crane to lower the Perseverance rover (illustrated here) to the martian surface. This complex landing system stands in contrast to the Skyfall concept, which aims to reduce risk by having its helicopters land themselves. NASA/JPL-CALTECH

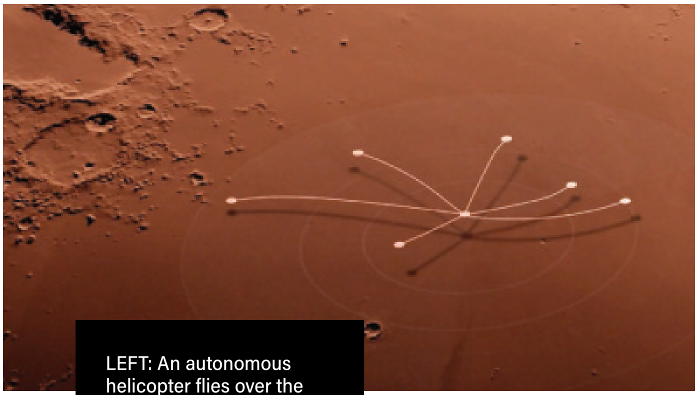
This concept is a direct evolution of the trailblazing Ingenuity helicopter, which hitched a ride to Mars' surface aboard the Perseverance rover in 2021 and became the first craft to achieve powered flight on another planet. AeroVironment collaborated with NASA's Jet Propulsion Laboratory (JPL) in Pasadena, California, to build Ingenuity, which carried out 72 flights as a scout for Perseverance before suffering mission-ending damage in early 2024.

A fleet of martian scouts

Ingenuity was a scrappy, eleventh-hour addition to its mission, built quickly and cheaply with a mindset that encouraged smart risks, says Pomerantz. For instance, its main flight computer ran off a commercial chip used in smartphones like the Samsung Galaxy S5. Ingenuity's success proved there was a "whole new way to explore Mars," says Pomerantz.

Skyfall scales that idea up, building an entire mission around a fleet of its descendants. Each of the six Skyfall helicopters would operate independently, creating a distributed network of explorers. Their primary mission would be to search for the safest, most resource-rich landing sites for the first human missions to Mars. Armed with high-resolution cameras and ground-penetrating radar, they would be looking for two criteria, says Pomerantz: a surface flat enough to prevent a large lander from tipping, and easy-to-access subsurface water ice. The ice would be a critical resource for both science and generating rocket fuel.





LEFT: An autonomous helicopter flies over the martian surface in this illustration. Each drone in the proposed six-craft swarm would be able to survey terrain faster and farther than ground-based rovers, exploring areas that are otherwise inaccessible. AEROVIRONMENT

RIGHT: Skyfall's six-helicopter swarm would fan out from a central deployment zone to explore Mars, as shown in this illustration. This distributed approach would allow the mission to cover a wide area more rapidly than a single vehicle could. AEROVIRONMENT

These objectives also align with NASA's science exploration strategy to "follow the water." Any location where water once flowed could harbor evidence of past life, making these ice deposits prime targets for future scientific missions.

The helicopters could also undertake extended science campaigns, exploring areas inaccessible to rovers. Pomerantz notes they could fly up cliff faces or even descend into "skylights" — openings to subsurface lava tube caves that are key science targets as well as potential human shelters.

The right tool for the job

Of course, these lightweight drones are not a replacement for a full-scale mobile science laboratory like Perseverance. (With a mass of 1.8 kilograms, Ingenuity weighed just 4 pounds on Earth, or 1.5 pounds in Mars' weaker gravity.)

To answer geological questions, "you need a payload of instruments that are too heavy for helicopters," says Melissa Rice, a planetary scientist at Western Washington University and a science team member for the Perseverance rover's Mastcam-Z camera system. Such instruments also require tools like drills and brushes to get under the layer of dust that covers the surface.

To replace scientific rovers entirely, drones would need to be scaled up to the size of a car, says Rice. One example of such an effort is NASA's nuclear-powered Dragonfly quadcopter, which is currently in development to explore Saturn's moon Titan. But building a martian equivalent would be a challenge: The air at Mars' surface is less than 1 percent the thickness of Earth's, providing much less lift for aircraft. By contrast, Titan's atmosphere is 50 percent thicker than Earth's, offering a much more forgiving flight environment.

Still, Rice sees huge advantages to rovers and helicopters working together on Mars. And the low payload capacity of helicopter drones is less of a concern if they are scouting for a human mission, she notes, as future astronauts could carry the necessary tools for detailed science investigations.

A flexible path forward

Skyfall's biggest obstacles may not be technical, but budgetary. "It's hard to envision how these exciting future possibilities can become a reality in the current budget climate," says Rice, pointing to the Trump administration's proposed cuts to NASA's science programs.

Pomerantz acknowledges the funding uncertainty, saying that "everybody's crystal ball is hazy right now," but he sees the mission's adaptable cost structure as a key strength. He expects the biggest expenses would be the launch and cruise stage — items common to any Mars mission. In contrast, the Skyfall-specific hardware would be "quite inexpensive, on the scale of planetary exploration missions." For comparison, the Ingenuity helicopter mission cost about $85 million, and Pomerantz says the Skyfall helicopters should be "substantially less expensive per helicopter."

This low per-unit cost makes the mission highly flexible. Skyfall's varied capabilities mean it could be funded in a variety of ways — as a traditional NASA-led mission, a more commercially-focused contract, or even a hybrid model. For instance, NASA's human exploration division might fund four helicopters to scout landing sites, while its science division funds two others to conduct research in a different region.

If funding is secured, Pomerantz thinks Skyfall could launch as soon as 2028. Due to the orbital mechanics of Earth and Mars, launch windows only open once every 26 months. "If we start soon-ish," hitting the 2028 window is achievable, he says.

Pomerantz's ultimate goal is to get Skyfall drones into the hands of the science community. He points to the American Geophysical Union conference this December as a key opportunity for collaboration, highlighting the meeting's special session on aerial exploration of Mars.

While personnel from AeroVironment and JPL will be present, Pomerantz stresses that the main objective is to foster collaboration among the researchers themselves, believing that "the best concepts will come from the open exchange of ideas!" He hopes to plant a seed in their minds, asking them to dream big: "What if you had your own helicopter on Mars? What would you want to do?"

Brooks Mendenhall *is an* Astronomy *magazine staff writer based in Chattanooga, Tennessee.*

Have you Found the Best Value in Travel?

Keel-billed Toucan

Explore Costa Rica on a fully guided tour with Caravan. Book now for choice dates: Caravan.com, 1-800-CARAVAN

Costa Rica 8-Day Tour $1195

Volcanoes, Beaches and Rainforests

Welcome to a great vacation at an affordable price. Caravan's quality tours feature complete sightseeing, professional Tour Directors, and great itineraries.

Your Costa Rica tour is fully guided and includes all meals, all hotels, and all activities. See exotic birds, view volcanoes, soak in hot springs, hike in a jungle rainforest, enjoy a wildlife river cruise, and stay three nights at one of the most beautiful beaches in Costa Rica.

The #1 in value. Enjoy complete sightseeing with more visits, extra features, and local guides. Caravan includes all activities listed in your tour itinerary. Caravan does not sell any optional activities which can add hundreds of dollars to the tour price. Join the smart shoppers and experienced travelers who have chosen Caravan Tours since 1952.

"Brilliant, Affordable Pricing"
Arthur Frommer, Travel Editor

Latin America Tours	**Days**	**Price**
Costa Rica	8	1195
Panama	8	1495
Guatemala	8	1295
Colombia	10	1695
Peru with Machu Picchu	8	1695
Mexico Copper Canyon Train	10	1895
Mexico Ancient Civilizations	10	1695
USA and Canada Tours		
Grand Canyon, Bryce & Zion		TBD
Mt. Rushmore & Yellowstone		TBD
New England & Fall Colors		TBD
Nova Scotia & Maritimes		TBD
Canadian Rockies & Glacier		TBD

Book now for choice dates.
Caravan.com
1-800-CARAVAN
Scan for details:

THE #1 IN VALUE—FULLY GUIDED TOURS SINCE 1952

caravan®

Available Only at Caravan.com or 1-800-CARAVAN

How we track near-Earth

Meet the planetary defenders who are on the hunt for the next big asteroid that could impact Earth.

BY RANDALL HYMAN

EARLY THIS YEAR, a surprise space rock made headlines around the globe when the International Asteroid Warning Network sounded its highest alarm since its creation in 2013. Threat levels for the newly discovered asteroid, named 2024 YR$_4$, were steadily increasing rather than waning, and experts estimated that the superyacht-sized rock had as much as a 1-in-33 chance of hitting Earth in just eight years. Its relatively long four-year orbit meant it would not be detectable again until 2028 on its final pass, leaving very little time for intervention.

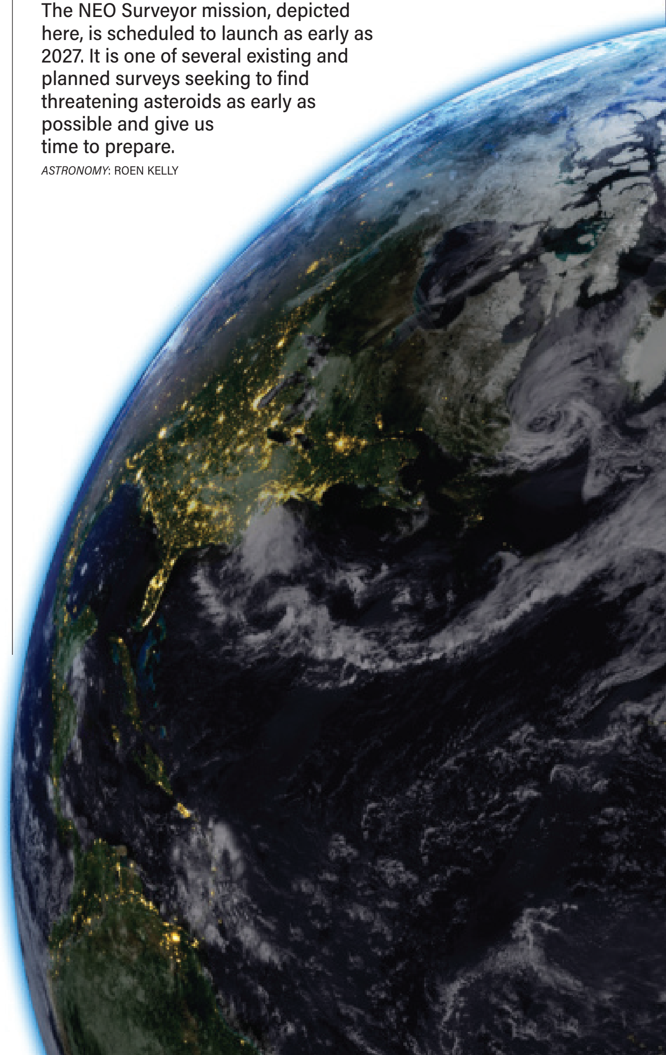
Scientists were concerned, but weeks of additional tracking granted a reprieve. Further data indicated that YR$_4$ would miss Earth, though still have a 1-in-25 chance of hitting the Moon in 2032. Relieved for the moment, astronomers nonetheless caution that a major impact by a large near-Earth asteroid (NEA) is just a matter of time.

Asteroids have pummeled Earth for eons — some with planet-changing consequences — but for the first time in human history, we have the technology to spot these threats before they arrive. A network of telescopes and their operators scan the skies as part of humanity's early warning system against hazardous asteroids, an effort known collectively as planetary defense. Their goal is to catalog and track every solar system rock headed our way that's large enough to flatten a city — not to mention end civilization as we know it.

Over the past few decades, astronomers have made slow but steady progress toward this goal with dedicated NEA surveys. New cutting-edge observatories like the Vera C. Rubin Observatory, which began operations earlier this year, are turbocharging these efforts, finally bringing it within reach.

Asteroid hunters

The modern era of planetary defense — a term coined by U.S. Air Force Lieutenant Colonel Lindley Johnson three decades ago — had its genesis after humanity had a ringside seat to a spectacular


The NEO Surveyor mission, depicted here, is scheduled to launch as early as 2027. It is one of several existing and planned surveys seeking to find threatening asteroids as early as possible and give us time to prepare.

ASTRONOMY: ROEN KELLY

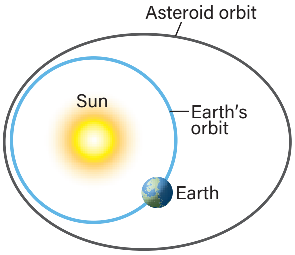
asteroids

NEA GROUPS

Amors

(named for 1221 Amor)
$a > 1.0$ AU
$1.017 < q < 1.3$ AU

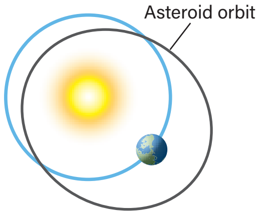
Amors are NEAs that have orbits approaching Earth's but lying entirely outside of it. They orbit between Earth and Mars.



Apollos

(named for 1862 Apollo)
$a > 1.0$ AU
$q < 1.017$ AU

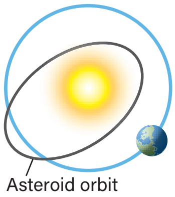
These are Earth-crossing NEAs whose orbits cross Earth's but spend most of their time outside it.



Atens

(named for 2062 Aten)
$a < 1.0$ AU
$Q > 0.983$ AU

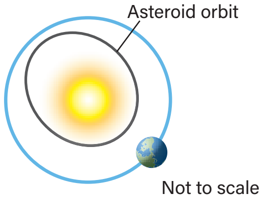
NEAs in this group have orbits that cross Earth's but spend most of their time inside it.



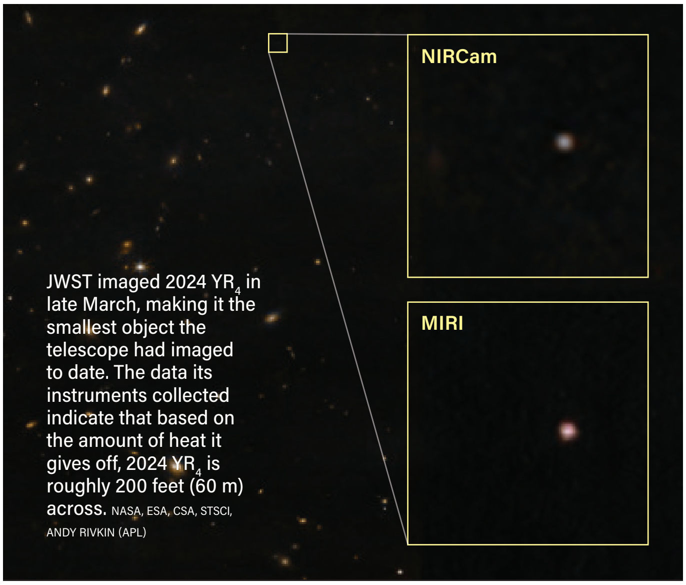
Atiras

(named for 163693 Atira)
$a < 1.0$ AU
$Q < 0.983$ AU

Atiras have orbits entirely contained within Earth's orbit, such that our orbits do not cross.



All NEAs by definition have a perihelion distance, or closest approach to the Sun, less than 1.3 astronomical units. (One astronomical unit, or AU, is the average Earth-Sun distance of 93 million miles [150 million km]). NEAs can be further separated into several groups, defined by orbital characteristics such as their perihelion distance, aphelion distance (farthest point from the Sun), and semi-major axis (roughly the object's average distance from the Sun). Each class of NEA is named for the first object discovered in a given group. Here, q is the perihelion distance, Q is the aphelion distance, and a is the semi-major axis. All distances are given in AU. NEAs are not considered PHAs unless they are both larger than 500 feet (140m) across and their orbit brings them within 0.05 AU or less of Earth. *ASTRONOMY*: ROEN KELLY, AFTER NASA/JPL-CALTECH



JWST imaged 2024 YR_4 in late March, making it the smallest object the telescope had imaged to date. The data its instruments collected indicate that based on the amount of heat it gives off, 2024 YR_4 is roughly 200 feet (60 m) across. NASA, ESA, CSA, STSCI, ANDY RIVKIN (APL)

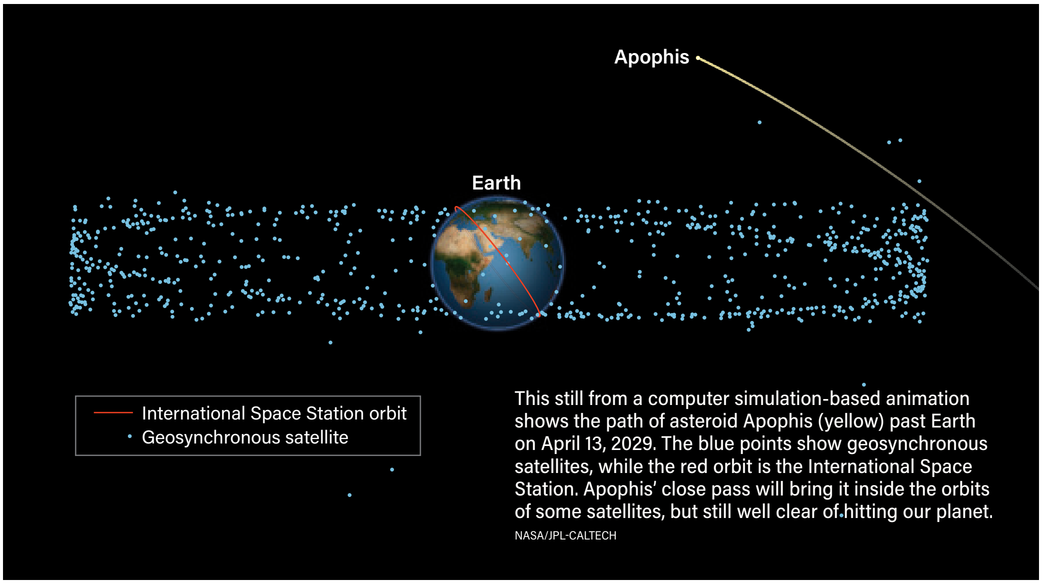
demonstration of cosmic violence. Discovered by legendary asteroid- and comet-hunting husband and wife Eugene and Carolyn Shoemaker, together with David Levy, Comet Shoemaker-Levy 9 barreled into Jupiter in 1994. A few fragments left atmospheric scars larger than Earth and packed punches 600 times more powerful than our planet's entire nuclear arsenal.

The event was a wake-up call for Congress and NASA, prompting the development of a comprehensive asteroid-search program under the auspices of what is now called the Planetary Defense Coordination Office. In 1998, Congress formalized this effort by ordering NASA to launch an all-out search for asteroids larger than 0.6 mile (1 kilometer) — the size threshold for global catastrophe. About 200 were known at the time, or some 20 percent of that total population, according to Paul Chodas, director of the Center for Near-Earth Object Studies (CNEOS) at NASA's Jet Propulsion Laboratory in California.

Since then, technology and tools have steadily improved, from film to digital detectors and from a handful of telescopes to an international network. Three full-time surveys — the Catalina Sky Survey (CSS) in Arizona; the Panoramic Survey Telescope and Rapid Response System (Pan-STARRS) in Hawaii; and the robotic Asteroid Terrestrial-impact Last Alert System (ATLAS) in Hawaii, Chile, and South Africa — now scour the skies year-round. They will soon be joined by the vast surveying capacity of the Vera C. Rubin Observatory in Chile, and in 2027 by the space-based infrared NEO Surveyor observatory. From space, NEO Surveyor will spot objects inside Earth's orbit using mid-infrared detectors that don't require an asteroid to reflect sunlight to make it detectable.

Eugene Shoemaker, who died in 1997, remains a touchstone of the community. "Gene gave me my mantra," says Greg Leonard, telescope operator for the CSS. Leonard represents a generation of asteroid hunters directly inspired by Shoemaker's work. As a young college graduate in 1992, he interned under Shoemaker, doing two-week stints at Mount Palomar searching for Earth-crossing asteroids and comets. He now spends most nights atop Mount Bigelow, northeast of Tucson, Arizona, searching for moving dots against thousands of stationary stars on a computer screen. "Gene told me that something is discovered for the first time only once, so put yourself in a position to discover," he says.

That is just what Leonard did when he joined the CSS 10 years ago with a background in geology and a love for astronomy. He discovered his own comet in 2021, C/2021 A1 (Leonard), which became known as the Christmas Comet and was featured in media worldwide.



This still from a computer simulation-based animation shows the path of asteroid Apophis (yellow) past Earth on April 13, 2029. The blue points show geosynchronous satellites, while the red orbit is the International Space Station. Apophis' close pass will bring it inside the orbits of some satellites, but still well clear of hitting our planet. NASA/JPL-CALTECH

Leonard and seven other full-time CSS observers use several telescopes outside Tucson — two full-time for searching and up to three for follow-up confirmations. The 27-inch Schmidt telescope Leonard operates can spot NEAs as small as a person 2 million miles (3.2 million km) distant — "a testament to the exquisite sensitivity of our CCD," the postcard-size digital sensor in the instrument.

"I spotted three candidates just last night [Nov. 9, 2024]," Leonard says, pointing to a sweep of monitors in the cramped control room. One screen displays a colorful chart that tracks the motions of the telescope whirring above us — 14-second exposures, repeated four times each, covering hundreds of fields, or roughly half the sky, per night. Imagery is constantly processed while the telescope slews — it takes 10 minutes from exposure to completion. Another telescope 4 miles (6.4 km) away atop Mount Lemmon specializes in dimmer objects — down to magnitude 22, a million times fainter than our eyes can see — and takes two weeks to cover half the sky.

Detection software and machine learning aid in the

RATING RISK

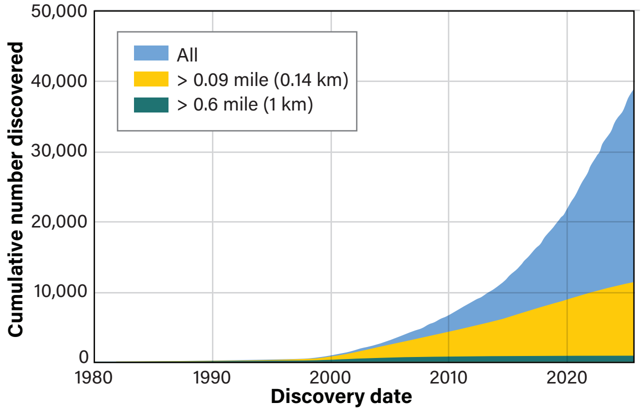
ASTRONOMERS RATE asteroid risk on the 10-point Torino Impact Hazard Scale, which uses colored tiers. White (0) and green (1) indicate effectively no chance of collision or a chance so small that it is of no concern. Yellow (2–4) designates asteroids with more than a 1 percent chance of collision, capable of inflicting localized destruction and warranting attention if the encounter will occur within a decade. Orange (5–7) identifies objects that pose a serious threat of regional destruction, with different levels warranting attention depending on the timing of the encounter (ranging from 10 to 100 years). Red (8–10) encompasses all definite collisions capable of causing destruction within any amount of time. Level 10, the highest rank on the scale, is reserved for extinction-level threats

Despite all the headlines, YR_4 at its worst rated a mere 3 on the Torino Scale. It is now 0. *—R.H.*

The Torino Impact Hazard Scale

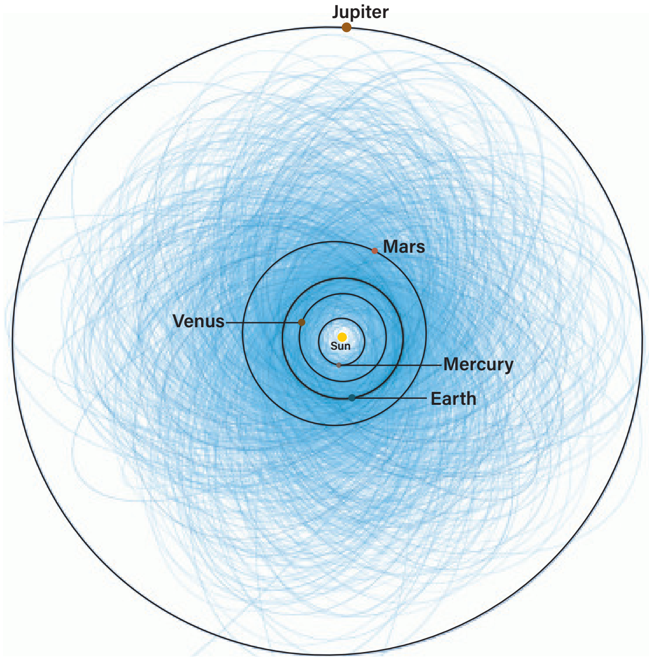
No hazard	0	The likelihood of a collision is zero or effectively zero. This includes objects that burn up in the atmosphere and meteorite falls, which rarely cause damage.
Normal	1	A pass near Earth is predicted but poses no unusual danger. Current calculations show a collision is extremely unlikely. No cause for public attention or concern. More observations very likely will lead to reassignment as Level 0.
Meriting astronomer attention	2	An object making a close but not highly unusual pass near Earth; a collision is very unlikely. May merit attention by astronomers but no public attention or concern. More observations very likely will lead to reassignment as Level 0.
	3	A close encounter with ≥ 1 percent chance of collision capable of localized destruction, meriting attention by astronomers. Attention by public or officials is merited if the encounter occurs within 10 years. More observations very likely will lead to reassignment as Level 0.
	4	A close encounter with ≥ 1 percent chance of collision capable of regional devastation, meriting attention by astronomers. Attention by public or officials is merited if the encounter occurs within 10 years. More observations very likely will lead to reassignment as Level 0.
Threatening	5	A close encounter posing a still-uncertain threat of regional devastation. Critical attention by astronomers is needed to determine conclusively whether a collision will occur. Governmental contingency planning may be warranted if the encounter occurs within 10 years.
	6	A close encounter by a large object posing a still-uncertain threat of a global catastrophe. Critical attention by astronomers is needed to determine conclusively whether a collision will occur. Governmental contingency planning may be warranted if the encounter occurs within 30 years.
	7	A very close encounter by a large object posing an unprecedented but still-uncertain threat of a global catastrophe if occurring within 100 years. International contingency planning is warranted, including to determine urgently and conclusively whether a collision will occur.
Certain collisions	8	A collision is certain, capable of localized destruction if over land or a tsunami if close offshore. Such events occur on average once per 50 to several thousand years.
	9	A collision is certain, capable of unprecedented regional devastation for a land impact or a major tsunami for an ocean impact. Such events occur on average once per 10,000 to 100,000 years.
	10	A collision is certain, capable of a global climatic catastrophe that may threaten civilization as we know it, regardless of impact site. Such events occur on average once per 100,000 years or more.

NEOs WE KNOW

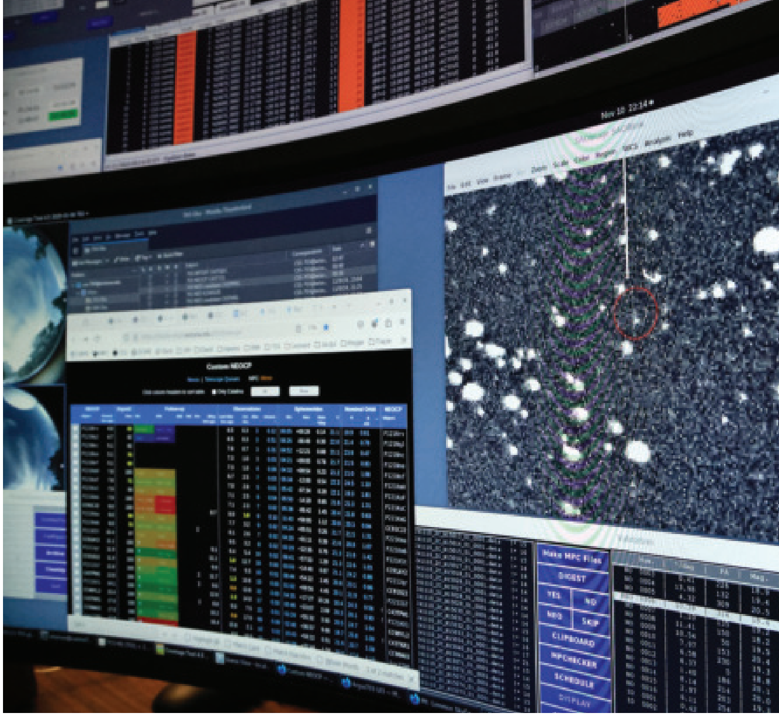


This graph shows the steep rise in the cumulative number of NEOs discovered over time. It includes all known NEOs as of Aug. 20, 2025. As of that date, there were 38,985 total known NEAs, with 11,382 of those larger than 0.09 mile (0.14 km) and 876 larger than 0.6 mile (1 km). Also at this time, 2,500 asteroids were classified as potentially hazardous (PHAs), including 155 PHAs larger than 0.6 mile (1 km). *ASTRONOMY*: ROEN KELLY, AFTER NASA/JPL-CALTECH

POTENTIALLY HAZARDOUS ASTEROIDS



This illustration shows the orbits of more than 1,400 PHAs (blue) identified as of early 2013. As of August this year, NASA CNEOS considered a total of 2,500 asteroids potentially hazardous to Earth. NASA/JPL-CALTECH



ABOVE: A red circle identifies one of two new NEOs discovered by Catalina Sky Survey telescope operator Greg Leonard Nov. 9, 2024, the day before the author visited the survey's facilities. This object is an Aten-family NEO with a diameter of about 164 feet (50 m), now officially designated 2024 VC$_3$. RANDALL HYMAN

RIGHT: Leonard explains the graphical display showing the Schmidt telescope's survey progress for the night. RANDALL HYMAN

search, but there is still an important human factor. Leonard pulls up an image from the previous night, featuring a riot of stars on a black field with a red circle pinpointing his discovery. A set of four photographs shows it changing position against a static field of stars — movement that Leonard noticed as he reviewed the images.

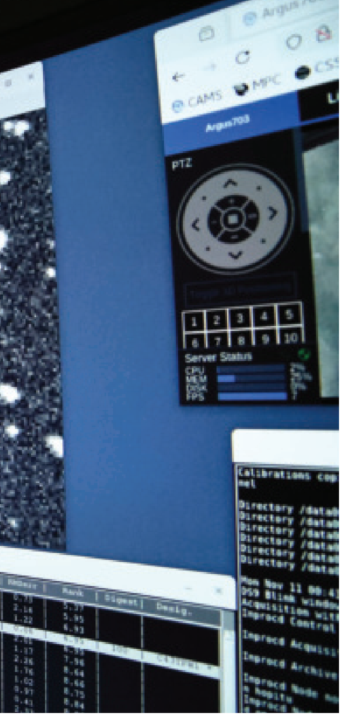
"Humans are integral to the Catalina Sky Survey," says CSS director Carson Fuls. "We manually review possible candidates because humans are highly adapted to detect slight motion."

By animating successive photos, observers can spot movement even when an object is very faint. If software and human agree on a find, detections are immediately submitted to the Harvard and Smithsonian Center for Astrophysics' Minor Planet Center (MPC) and posted worldwide to allow other observatories to double-check the sightings. The rapid pace is vital: The optical visibility of an asteroid depends not only on its position but also those of Earth and the Sun, and that geometry can change quickly. "What matters with discovery of near-Earth objects is how fast you can report it so someone else can follow up to do targeted observations, because otherwise, it's gone," says Fuls.

Once the MPC confirms a detection (provided it isn't dismissed it as an artifact, space junk, or a previously known near-Earth object [NEO]) it names them — all within 24 hours.

According to Fuls, the CSS vets the 20 most likely asteroid candidates in each of the hundreds of fields per night. "Reviews of aggregate historical data show that 98 percent of detected NEOs are ranked in [these] top 20 potential detections," says Fuls. "But that leaves dozens in each field we don't have time for."

To address that gap, the CSS posts nightly imagery for the next 20 most likely candidates for the public to review on the Zooniverse citizen science platform as part of The Daily Minor Planet project. More than 7,000 citizen scientists have logged on to try their hand at asteroid hunting since the project's inception in October 2023, spotting some



3,500 previously undetected asteroids and discovering three new NEOs.

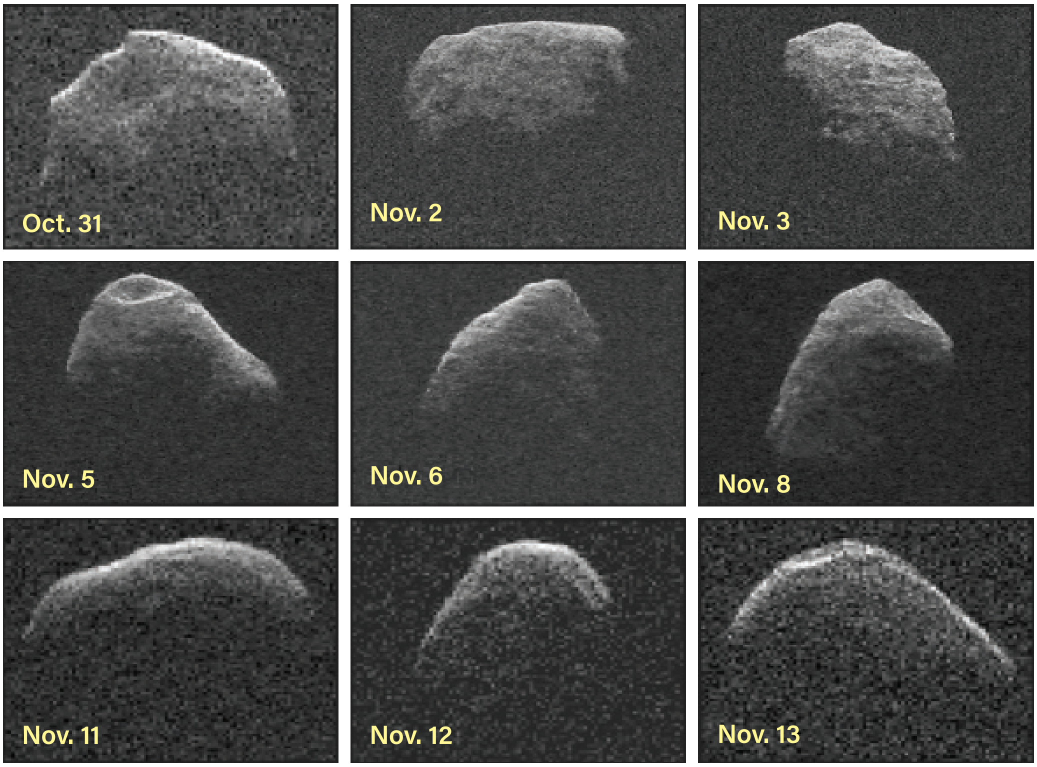
Fuls says that the introduction of the Rubin Observatory will help discover even more NEOs. And Mario Juric, head of Rubin's LSST Solar System Pipeline Group, adds, "As we [Rubin] come online, my bet is the entire planetary defense discovery system will be reoptimized to draw on specific strengths of each program and the whole will be much more powerful than any individual piece."

Near-Earth asteroids

NEOs, which include NEAs, are asteroids or comets that orbit the Sun with a perihelion, or closest point to the Sun, of 1.3 astronomical units or less. (One astronomical unit, or AU, is the average Earth-Sun distance of 93 million miles [150 million km].) If an asteroid exceeds 460 feet (0.09 mile; 140 m) in width and comes within about 4.6 million miles (7.5 million km; 0.05 AU) of Earth's orbital path, it is designated a potentially hazardous asteroid (PHA), capable of widespread destruction.

In seeking to fulfill Congress' mandate to search for asteroids larger than 0.6 mile (3,168 feet; 1 km), CSS and other surveys face a daunting task. "There's on the order of 24,000 NEAs that are 140 meters [460 feet] and larger, depending on how you count them," says Chodas. "We've found 9,600 NEAs and about 900 that are larger than 1 kilometer [0.6 mile], but by that measure, we're not even halfway," he says.

That's because determining how many total NEAs exist is tricky. "The percentage of NEAs that have been discovered so far depends tremendously on size," Chodas explains. "I give the example of a bunch of fish in a small lake. The fish are like asteroids. When you go fishing, you tag



These nine views of the Apollo-group NEA 2007 PA$_8$ were obtained in October and November 2012 by NASA's Deep Space Network antenna in Goldstone, California. 2007 PA$_8$ measures about 1 mile (1.6 km) across, and although its orbit crosses our own, is not considered a hazard to Earth. NASA/JPL-CALTECH them as you catch them [and] throw them back in. You do this day after day, and after a month or two, when 90 percent of the fish you're catching are tagged, you know you've found 90 percent of the population. But the smaller the size limit you're interested in, the larger the population, and the smaller the completion ratio."

In 2005, NASA was directed by Congress to more specifically identify 90 percent of NEOs larger than 460 feet (140 m); Chodas says some 45 percent of the expected population has been identified. But "the population number rises exponentially as [you] go to smaller threshold sizes: The population is roughly 100,000 at the size of 2024 YR$_4$ (which was about 60 m [197 feet] in size), and if we go all the way down to a few meters in size, the population of NEAs is over a billion."

Crash avoidance

For Chodas, the real challenge is determining trajectories, not numbers. He has been predicting the motions of asteroids and comets with pinpoint accuracy for decades. Chodas is also tasked with inventing the fictional asteroids for Planetary Defense Conferences — a biennial forum for thwarting hypothetical killer space rocks, akin to war games for astronomers and engineers.

CNEOS determines impact threat for all reported NEOs — even candidates that have not yet been confirmed. Objects in the MPC's database of candidates are evaluated by CNEOS' Scout software, which performs preliminary trajectory and threat analysis to identify short-term, imminent impactors. The MPC also operates the Sentry system, which looks at the confirmed asteroid catalog to assess whether an impact is possible in the next 100 years. Both systems continually update risk assessments as additional data come in.

For several weeks after YR$_4$ was discovered by ATLAS in Chile around Christmas 2024, the risk of impact kept rising with more data rather than diminishing, triggering alarm. Coincidentally, the hypothetical asteroid for this year's Planetary Defense Conference in May was eerily similar to YR$_4$ in projected size and impact probability, even though it was invented months before YR$_4$'s discovery. The uncanny similarity underlined how vital such "war games" can be, a reminder to scientists that inevitably their efforts will not be a mere drill.

Cosmic shooting gallery

Earth was once a frequent victim of NEOs, though our scars are hidden by eons of erosion, uplift, and sedimentation. Today, the number of potential impactors in our vicinity is far fewer than in the solar system's youth. But a single strike like the 2013 Chelyabinsk meteor over Russia — an unexpected 10,000-ton asteroid that snuck in from behind the Sun and exploded high in the stratosphere with 30 times the energy of a small atomic bomb — reminds us that we are still whirling through a cosmic shooting gallery.

We are becoming better prepared. "We've predicted impacts to within a few seconds and within a kilometer with just a few hours' warning," says Chodas, referring to hits in Sudan in 2008 and western Europe in 2023 and 2024. "We got out the predictions, and people actually filmed fireballs coming through the atmosphere."

Still, a spectacular reminder of our vulnerability is just around the corner. In April 2029, Earth will experience a remarkably intimate visit from an asteroid the size of an aircraft carrier passing much closer than the Moon. It will be a once-in-a-millennium occurrence: an asteroid visible with the naked eye, sure to create sensational headlines.

Discovered in 2004, 99942 Apophis (named after the monstrous Egyptian serpent god intent on disrupting the cycle of night and day) will pass within 20,000 miles (32,000 km) of Earth, closer than many satellites in geosynchronous orbit. Based on extensive observations and

THE DOUBLE ASTEROID REDIRECTION TEST

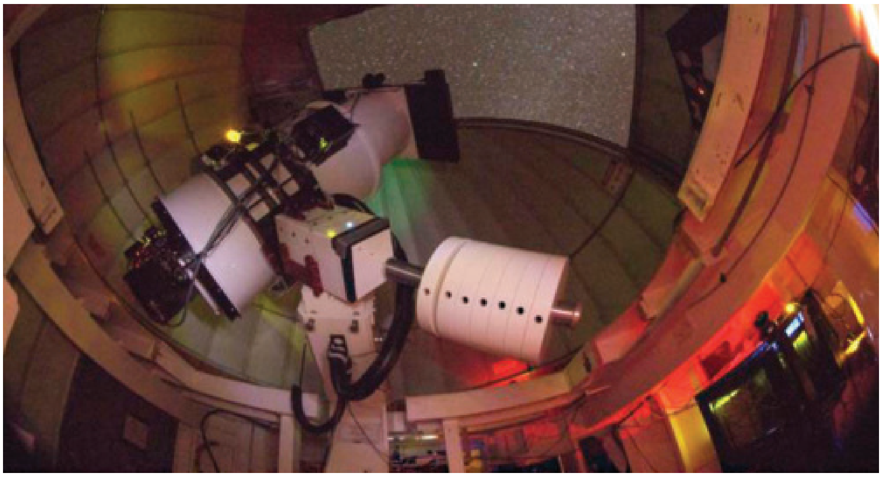
UNTIL RECENTLY, humans were no better prepared to ward off killer asteroids than the dinosaurs. That changed in September 2022, when NASA's roughly half-ton Double Asteroid Redirection Test (DART) spacecraft smashed into the 525-foot (160 m), 5.5-million-ton asteroid Dimorphos at nearly 14,000 mph (22,500 km/h), generating the energy of three tons of TNT.

Each tiny speckle in this December 2022 Hubble image of the asteroid Dimorphos (bright object at lower left) is a boulder knocked off the asteroid during the DART spacecraft impact three months prior. The rocks imaged here are some 3 to 22 feet (1 to 6.7 m) across, spotted drifting away from Dimorphos at around 0.6 mph (1 km/h). Such debris could be of concern during future efforts to redirect an asteroid threatening Earth. NASA, ESA, D. JEWITT (UCLA) (CC BY 4.0 INT)

Dimorphos orbits an asteroid five times its size, called Didymos. Astronomers used this to track the result of the impact by watching the pair's orbital period shrink after the nudge. The impact ultimately shortened the system's orbital tango by 32 minutes.

Compared to the tens of miles per second at which Dimorphos whips around the Sun, this is a tiny fraction of its momentum — tenths of an inch per second. According to David Jewitt, an astronomer at the University of California, Los Angeles, who published a study about DART's aftermath in July 2023, any useful deflection of a larger asteroid would require a far greater shove or need to occur decades ahead of an impending collision to have a cumulative effect. "If you wanted to deflect a bigger asteroid — for example, something 10 times larger — you'd need 1,000 DARTs to get the same minuscule deflection," he says.

A larger impact, however, means more debris. And in the case of an asteroid headed for Earth, that debris could spell trouble, raining down on the planet even if the larger impactor doesn't. Months after the collision, Jewitt and colleagues discovered a swarm of boulders from Dimorphos in Hubble imagery, some as large as houses, drifting away in all directions. They are now waiting for ESA's Hera spacecraft to rendezvous with Didymos in late 2026 to find out the fate of this debris. *—R.H.*



Telescopes of the Asteroid Terrestrial-impact Last Alert System (left) in Hawaii, the Panoramic Survey Telescope and Rapid Response System (top), and the Catalina Sky Survey in Arizona (above) scour the skies looking for new NEOs that could pose a threat to Earth. ATLAS: HENRY WEILAND; PAN-STARRS: UNIVERSITY OF HAWAI'I; CSS: DAVID RANKIN

calculations, experts like Chodas have determined that it will harmlessly glide by and not pose a threat for at least 100 years.

Space agencies are excitedly preparing for this exceptional encounter with a PHA. NASA has reconfigured its Origins, Spectral Interpretation, Resource Identification, and Security — Regolith Explorer (OSIRIS-REx) mission, which previously returned samples from asteroid 101955 Bennu, as the OSIRIS-APophis EXplorer (OSIRIS-APEX) with a new goal: to rendezvous with Apophis. With fuel already low, it can only fly by Apophis. The European Space Agency, on the other hand, hopes to redirect Hera after its visit to the asteroid Didymos to study the aftereffects of NASA's Double Asteroid Redirection Test (DART). Under the new name the Rapid Apophis Mission for Space Safety (Ramses), it will rendezvous with Apophis before the asteroid flies by Earth and remain with it throughout its pass.

Both missions will offer deep insights into how Earth's tidal forces interact with incoming space rocks. Combined with new surveys like Rubin's and dedicated observers like Leonard and Chodas, scientists are getting ever closer to the ability to plan for the next uninvited guest to crash the party, and to hopefully thwart its mission of chaos and doom.

Randall Hyman *is a science writer whose work has been featured in numerous publications, including* Nature, Science, *and* Smithsonian.

A farewell to Jim Lo

Two Gemini and two Apollo flights cemented this trailblazing astronaut's place in history.

BY RICHARD TALCOTT

THE WORLD LOST A TRUE HERO Aug. 7, when astronaut and space pioneer Jim Lovell passed away at age 97. The first person to fly in space four times, Lovell helped pave the way for the first Moon landing and came to epitomize NASA's can-do attitude.

I had the honor and pleasure to interview Lovell three times during the latter half of the 2010s. Always gracious, humorous, and engaging, he became a good — dare I say it — friend. What follows is a remembrance, sprinkled with his reflections culled from our interviews.

The early years

James Arthur Lovell Jr. was born in Cleveland on March 25, 1928. After his father died in a car accident in 1933, he and his mother moved to Terre Haute, Indiana, where they lived with a relative for two years. Lovell spent his formative years in Milwaukee. He excelled in school

← Jim Lovell poses for his formal portrait four months before the April 1970 launch of Apollo 13. The mission's intended target — the lunar crater Fra Mauro — sits near the Moon globe's center. NASA and became an Eagle Scout, yet still found time to study rocketry and build model rockets.

Finances were tight in the Lovell household, and Jim had few options to continue his education after high school. Enter the U.S. Navy. Although the prestigious and selective Naval Academy rejected Lovell's application, the service had just initiated a program that provided two years of free college tuition to study engineering. Flight training and a year of active duty followed. The students were then allowed to complete their degrees before becoming naval aviators.

Lovell completed his two years at the University of Wisconsin–Madison, but then reapplied to the Naval Academy at the urging of his mother, who feared that an outbreak of war could unduly delay his education. The second time proved to be the charm. He graduated in 1952 and soon started flight training in Pensacola, Florida. Fourteen months later, he officially became a naval aviator and began flying night missions off aircraft carriers in the Pacific.

Gemini astronaut

Although Lovell was happy as a carrier pilot and later instructor, by 1957 that career had lost some of its excitement. He applied for a transfer to the Naval Air Station in Patuxent River, Maryland, where he planned to test experimental aircraft. But the ground beneath aviation was shaken to its core Oct. 4, 1957, when the Soviet Union launched Sputnik into Earth orbit. Suddenly, the horizon aviators could envision stretched far beyond Earth's atmosphere.

Lovell set his sights on becoming an astronaut, and in 1958 he was one of 110 test pilots selected as candidates for the Mercury program. Like his initial rejection from the Naval Academy, he didn't make the cut. A high count of a liver compound meant he wouldn't be one of the Mercury Seven, the group who would make America's first forays into space.

Of course, seven astronauts wouldn't be able to crew all of the planned two-man Gemini and three-man Apollo flights. NASA started recruiting a second astronaut group in 1962 and, this time, Lovell made it. He joined eight other winners in the so-called "Next Nine" or "New Nine," a veritable who's who of astronauts destined to achieve President Kennedy's goal of "landing a man on the Moon and returning him safely to the Earth."

The Gemini program was designed to test every procedure needed to realize Kennedy's objective. Ten crewed flights in 20 months demonstrated astronauts' abilities to rendezvous and dock two spacecraft; start, stop, and restart rocket engines; function productively outside a spacecraft; and, most importantly, live in space for an extended period.

Lovell's two Gemini flights played critical roles in achieving these milestones. In December 1965, Gemini VII — NASA was as fond of using Roman numerals for the Gemini flights as the NFL is in numbering Super Bowls — sent Lovell and Frank Borman into Earth orbit for 14 days, longer than any of the Apollo Moon missions. The two astronauts also participated in the first rendezvous with another crewed mission when they met Gemini VI-A and flew in tandem with the other ship for three orbits.

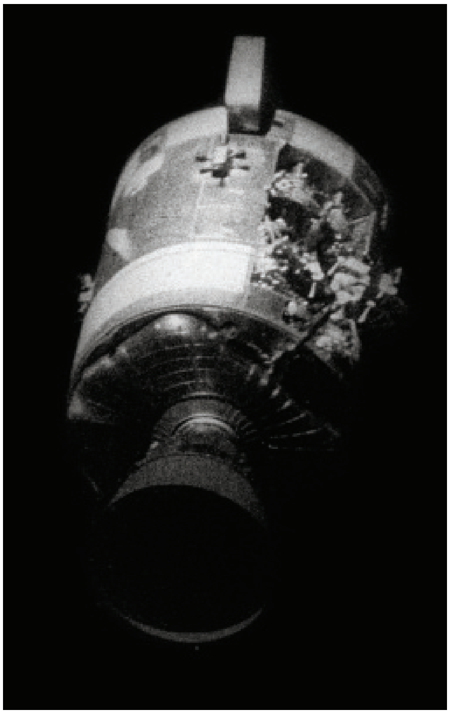
The final mission in the program, Gemini XII, came in November 1966. Lovell teamed with Buzz Aldrin on this four-day flight that proved humans could work outside the spacecraft. Although four NASA astronauts — Ed White, Gene Cernan, Michael Collins, and Dick Gordon — previously had performed spacewalks, none went particularly well. But Aldrin equipped himself with special tethers, foot restraints, and portable handholds, buzzing around the space capsule as if on a walk in the park.

To the Moon

Lovell would not fly again for two years. The tragic launchpad fire that killed the Apollo 1 crew — Gus Grissom, White, and Roger Chaffee — on Jan. 27, 1967, forced NASA to delay the program while the agency figured out what went wrong and then redesigned the spacecraft's command module. Flights resumed with Apollo 7 in October 1968. Lovell would get his next opportunity two months later on Apollo 8.

The historic mission to the Moon hadn't been planned that way. NASA originally conceived Apollo 8 as a test flight for the lunar module in low Earth orbit, following on Apollo 7's successful test of the command and service modules.

↓ An oxygen tank exploded during Apollo 13's flight to the Moon, crippling the spacecraft. The blast blew away a service module panel, seen here after the astronauts jettisoned the module just before reentering Earth's atmosphere. NASA



ovell

↑ Astronauts Jim Lovell (left) and Frank Borman, in their T-38 jumpsuits and helmets, stand behind a model of their Gemini VII space capsule several months before its December 1965 flight. NASA

But the lunar module program was running behind schedule and wasn't ready for Apollo 8. NASA made the bold move to swap the crews of Apollos 8 and 9, and fly 8 to the Moon. "I guess there's a certain amount of luck in everybody's life," said Lovell, who joined Gemini VII crewmate Borman and rookie astronaut Bill Anders on the Apollo 8 crew.

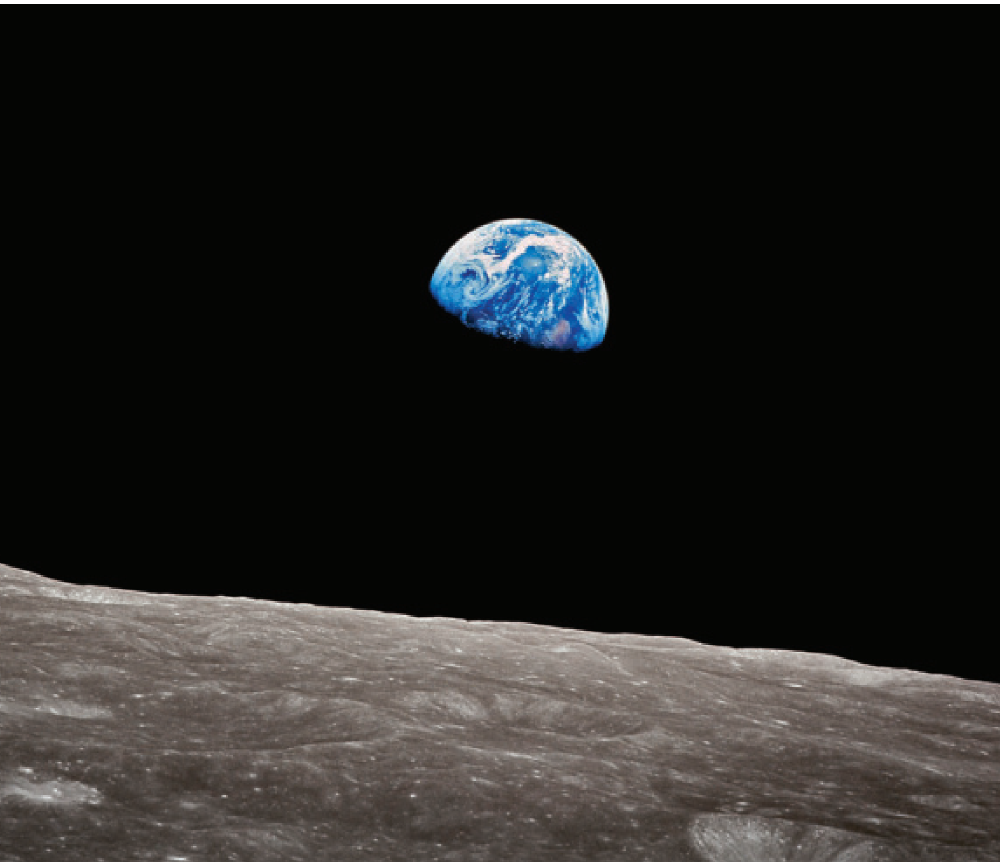
Assassinations, riots, and an unpopular war had dominated the news in 1968. But these three men were about to change the year's grim narrative. On the morning of Dec. 21, Apollo 8 lifted off from Florida's Kennedy Space Center on top of the powerful Saturn V rocket. A few hours later, the crew became the first humans to slip the bonds of Earth's gravity when they lit the Saturn V's third stage.

Three days later, Apollo 8 fired its service module engine and entered the first of its 10 lunar orbits. Lovell told me his most profound memory of the lunar visit was his new perspective on Earth: "When I looked out at the Earth for the first time, 240,000 miles away, my world suddenly expanded to infinity. I could put my thumb up to the window and completely hide the Earth. And I suddenly realized that behind my thumb, on this little planet, was about 5 billion people. Everything I ever knew was behind my thumb."

Lunar orbit also brought the astronauts' iconic reading of the first 10 verses from Genesis. And it gave Lovell his first close-up look at Mount Marilyn. He had spotted this triangular-shaped peak during training and thought it might make a good reference point for the Apollo 11 astronauts who would land on the adjacent Sea of Tranquillity. He unofficially named it after his wife, Marilyn Lillie Lovell, who would remain married to Jim for 71 years until her death in 2023.

In a mission filled with firsts, perhaps the most memorable is a single image called "Earthrise." It showed a stark lunar landscape with a beautiful blue planet

Perhaps the most memorable first is a single image called "Earthrise." It showed a stark lunar landscape with a beautiful blue planet hanging in the blackness of space, capturing the fragility and isolation of our home planet.



↓ Earth rises over the Moon's limb as Apollo 8 comes out from behind the Moon. The lunar horizon lay approximately 485 miles (780 km) from the spacecraft when Bill Anders captured the scene. NASA hanging in the blackness of space, capturing the fragility and isolation of our home planet. Although Anders was the mission photographer, Lovell was quick to point out the alignment to him. "When the Earth drifted over to my window and I looked at it and saw the composition of the Earth with respect to the lunar horizon, I said, 'Bill, this is it. This is the picture.'"

Houston, we've had a problem

With the successful landings of Apollos 11 and 12, spaceflight had become routine, if not a little boring, for many Americans. Apollo 13 would change that in an instant. Once again, fate played a role. Lovell was initially scheduled to go back to the Moon on Apollo 14, but NASA decided that 13's slated commander, Alan Shepard, didn't have enough training and swapped crews.

Lovell and rookie crewmates Jack Swigert and Fred Haise lifted off April 11, 1970, for what was supposed to be the first lunar mission to concentrate on science. Although not a superstitious guy who believed the number 13 was unlucky, Lovell told me, "As you look at the flight and you analyze the mission from its inception to the finish, you'll see that it was plagued by bad omens and bad luck."

Jack Swigert only made the crew because original member Ken Mattingly had been exposed to the German measles, and he was the only crew member not immune from prior exposure. In addition, one of the ship's oxygen tanks had been damaged earlier and, though apparently repaired, was still behaving oddly. Then, less than six minutes into the flight, one of the engines shut down two minutes prematurely. The other engines managed to compensate, however, and all seemed well as the crew headed toward the Moon.

That changed two days later, on April 13. Some 200,000 miles from Earth, the damaged oxygen tank exploded during a routine stirring. It caused the other tank to fail, and cascading events left the command module without its supply of electricity, light, and water. Most people would have panicked. But Lovell and his crewmates were former test pilots, and they knew how to handle adversity.

Along with mission control, they figured out solutions. First, they would use the lunar module as a lifeboat to get back. Second, they had to alter the spacecraft's course, which was designed to get them into lunar orbit, to get on a free-return trajectory. Then, they had to speed up to get back to Earth before their supplies ran out.

Maneuvering proved to be a big problem. NASA didn't design the lunar module to fly while attached to the command and service modules. Yet they couldn't jettison the command module because they needed its heat shield to protect them during reentry. "The center of gravity, instead of being in the center of the lunar module like it is normally, was way out in left field someplace," said Lovell. "So, I literally had to learn by the [way it handled] how to maneuver. Fortunately, when you're in deep trouble, you learn pretty fast."

The other major problem was the buildup of carbon dioxide. "The lithium-hydroxide canisters [on the lunar module] were designed to remove carbon dioxide from two people for two days, and we were three people for four days," said Lovell. "It meant that we had to take a square canister from the command module and rig it into the environmental system of the lunar module, which used round canisters that went into round holes. We ended up using duct tape, plastic, a piece of cardboard, and an old sock to jury-rig [a] system to remove the carbon dioxide."

The crew made it safely back to Earth on April 17. They received a hero's welcome, a far cry from the ho-hum reaction to their liftoff.

Jim Lovell gave hundreds of interviews over the years, and I was privileged to conduct three of them. His warmth, insight, and down-to-Earth humor came through in every response. I consider my time with him a highlight of my 40-year career at *Astronomy*.

On July 26, 2017, nearly 50 years after Lovell's Apollo flights, the International Astronomical Union recognized Mount Marilyn as the official name for that peak on the Sea of Tranquillity's edge. As he told me in 2018, "From that day on, in perpetuity, looking down at me long after I'm gone, will be this little triangular mountain named Mount Marilyn." May our memory of Jim Lovell and his fellow space pioneers survive as long.

Contributing Editor **Richard Talcott** *intently followed all the trials and triumphs of the Gemini and Apollo programs.*

Lovell chatted with me and the *Astronomy* staff in August 2019 at the Lake Forest, Illinois, public library. *ASTRONOMY*: DAVID J. EICHER

SKY THIS MONTH

👁 Visible to the naked eye
Visible with binoculars
Visible with a telescope

THE SOLAR SYSTEM'S CHANGING LANDSCAPE AS IT APPEARS IN EARTH'S SKY.

BY MARTIN RATCLIFFE AND ALISTER LING

Geminid meteors stream from the radiant in Gemini in this composite, complete with the aurora borealis at left, which appeared later in the night. ALAN DYER

DECEMBER 2025

The Geminids put on a show

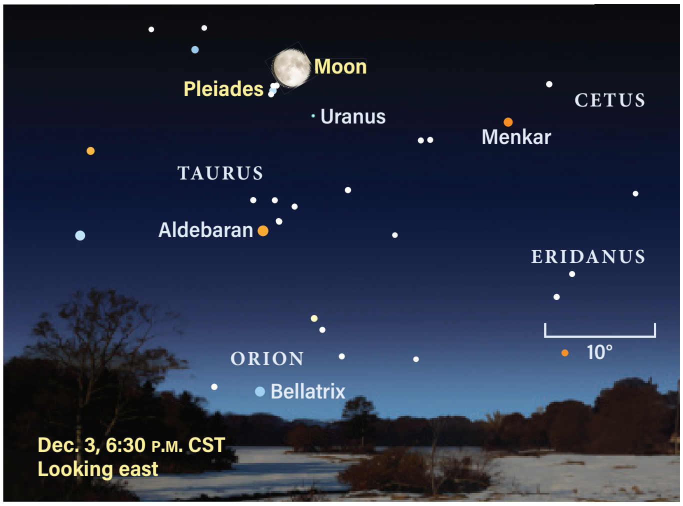
» The long nights of December are an astronomical delight. The early evening sky hosts Saturn as the main feature, along with Uranus and Neptune. Jupiter rises later and is visible all night, its four main satellites undergoing many notable events. The morning sky shows the best Northern Hemisphere appearance of Mercury for the year.

Let's begin with **Saturn** and **Neptune**, 4.3° apart on Dec. 1. Saturn's easterly motion carries it to within 3.5° of Neptune by the 31st. Saturn is easy to spot at magnitude 1.0 — the brightest object in the region except when the Moon passes by Dec. 26. Both planets stand 45° high in the southern sky as soon as it's dark and set by midnight, so plan to observe in early evening.

Neptune shines at magnitude 7.7 and requires at least binoculars to view. Saturn's proximity makes it easy to spot. About half a binocular field of view east of Saturn lies 5th-magnitude 27 Piscium, and Neptune is 2° north of this star.

Neptune spans 2" through a telescope and its bluish-hued disk appears nonstellar. It lies 2.8 billion miles from Earth.

Passing through



Dec. 3, 6:30 P.M. CST
Looking east

One day from Full, the Moon closes in on the Pleiades for an occultation the night of Dec. 3. Uranus will require optical aid to view. ALL ILLUSTRATIONS: *ASTRONOMY:* ROEN KELLY

At the end of the year, Saturn is 902.6 million miles from Earth and its disk spans 17". The edge-on rings give us a rare chance to see both hemispheres at once. The rings open slightly from 0.4° to 1.0° during the month.

Eighth-magnitude Titan, Saturn's largest moon, wanders back and forth every week. You'll find it near Saturn Dec. 8, 16, and 24. Titan transits Saturn twice, though neither is visible from the U.S. European observers can enjoy the first transit Dec. 8 beginning at 17:37 UT and the second Dec. 24 beginning at 16:58 UT. Each ends about six hours later. The moon reappears from occultation Dec. 16 around 21:56 UT, again visible in Europe and the U.K.

Tethys, Dione, and Rhea,

OBSERVING HIGHLIGHT

MERCURY is at its best for the year in the Northern Hemisphere morning sky, reaching greatest western elongation Dec. 7.

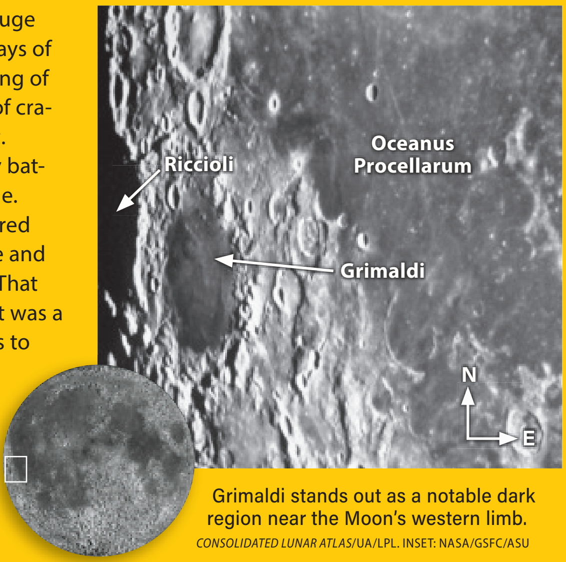
RISING MOON | Westward ho

THE LAVA-FILLED GRIMALDI BASIN is easily identified on the western limb of the Moon as the last patch of darkness west of the huge Oceanus Procellarum. But when the first rays of sunlight tickle its clumpy rim on the evening of the 3rd, only a "Mickey Mouse head" trio of craters points the way in the lunar southwest.

Fully illuminated on the 4th, the highly battered crater rim is direct evidence of its age. Several interesting sights have also appeared next to Grimaldi, notably the equally large and battered Riccioli closer to the terminator. That crater has a much rougher floor because it was a little too far from Procellarum's lava floods to get filled up like Grimaldi.

Use a dark filter on your eyepiece to reduce the stark brightness levels of the Full Moon. If you don't have one, just crank up the power to spread out the light and you'll find the result a lot easier on the eye. Spend some time here to note that Grimaldi's floor is not a uniform shade. See if you can follow the indistinct rays of lighter rock ejected from a couple of major impacts late in the Moon's bombardment back to their source.

Grimaldi



Grimaldi stands out as a notable dark region near the Moon's western limb.

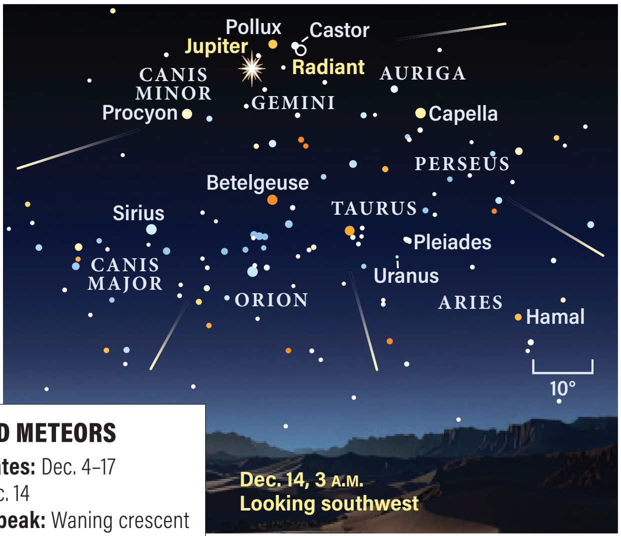
CONSOLIDATED LUNAR ATLAS/UA/LPL. INSET: NASA/GSFC/ASU

A bonus feature: On Dec. 1, check out the Marius Hills along the terminator just north of the equator.

Sunrise will return to Grimaldi Jan. 1.

METEOR WATCH | End the year with a bang

Geminid meteor shower



Dec. 14, 3 A.M.
Looking southwest

The Geminid meteor shower is active from Dec. 4 to 17, so follow it for a few nights for the best results.

GEMINID METEORS

Active dates: Dec. 4–17
Peak: Dec. 14
Moon at peak: Waning crescent
Maximum rate at peak:
150 meteors/hour

THERE'S A WANING CRESCENT MOON three days past Last Quarter as the Geminid meteor shower peaks. While the Moon will subdue fainter meteors, the Geminids are well known for brilliant members and given that Gemini is very high near local midnight, meteors can be observed anywhere across the sky. The zenithal hourly rate is over 100, and the shower is regarded as the best one of the year, so even with the Moon around you should see quite a few meteors every hour.

The second major shower in December is the Ursids, active from Dec. 17–26 and peaking the 22nd. There's no interference from the Moon, although rates are one-tenth that of the Geminids. With the radiant up all night, however, there's a good chance that you will spot some of its shower members.

each shining at 10th magnitude, orbit Saturn closer than Titan. With the rings nearly edge-on, it's fascinating to watch these moons for close conjunctions.

For example: Dione stands 1" due north of Tethys on the 9th, and you can see their relative motion between 10 and 11 P.M. EST. On the 15th, Dione stands 2" due north of Titan an hour earlier. These events are close to the resolution limit of smaller telescopes and will be affected by any local atmospheric turbulence. On the 16th, Tethys and Titan stand 2" apart near the eastern edge of the rings just after 9 P.M. EST. On the 17th, Dione and Tethys meet again near Saturn's western limb — the pair appears to merge just before 9 P.M. EST as they approach closer than 1", although Tethys is on the far side of the rings and is occulted by them, so it may appear fainter or disappear entirely depending on seeing conditions.

The dim rings may allow you to view magnitude 11.8 Enceladus. It remains within about 37" of Saturn, or 15" from the edges of the rings.

Iapetus reaches superior conjunction with Saturn Dec. 6. U.S. observers will see the 11th-magnitude moon 1.2' due south of the planet the evening of the 5th. Its then reaches its eastern (fainter) elongation on the 25th, dipping to 12th magnitude.

Uranus spends all month in Taurus, located south of the Pleiades (M45). The planet is very easy to spot as it wanders south of a pair of 6th-magnitude stars, 13 and 14 Tauri. As December opens, Uranus is in line with the pair, standing a Moon's width due

— Continued on page 34

STAR DOME

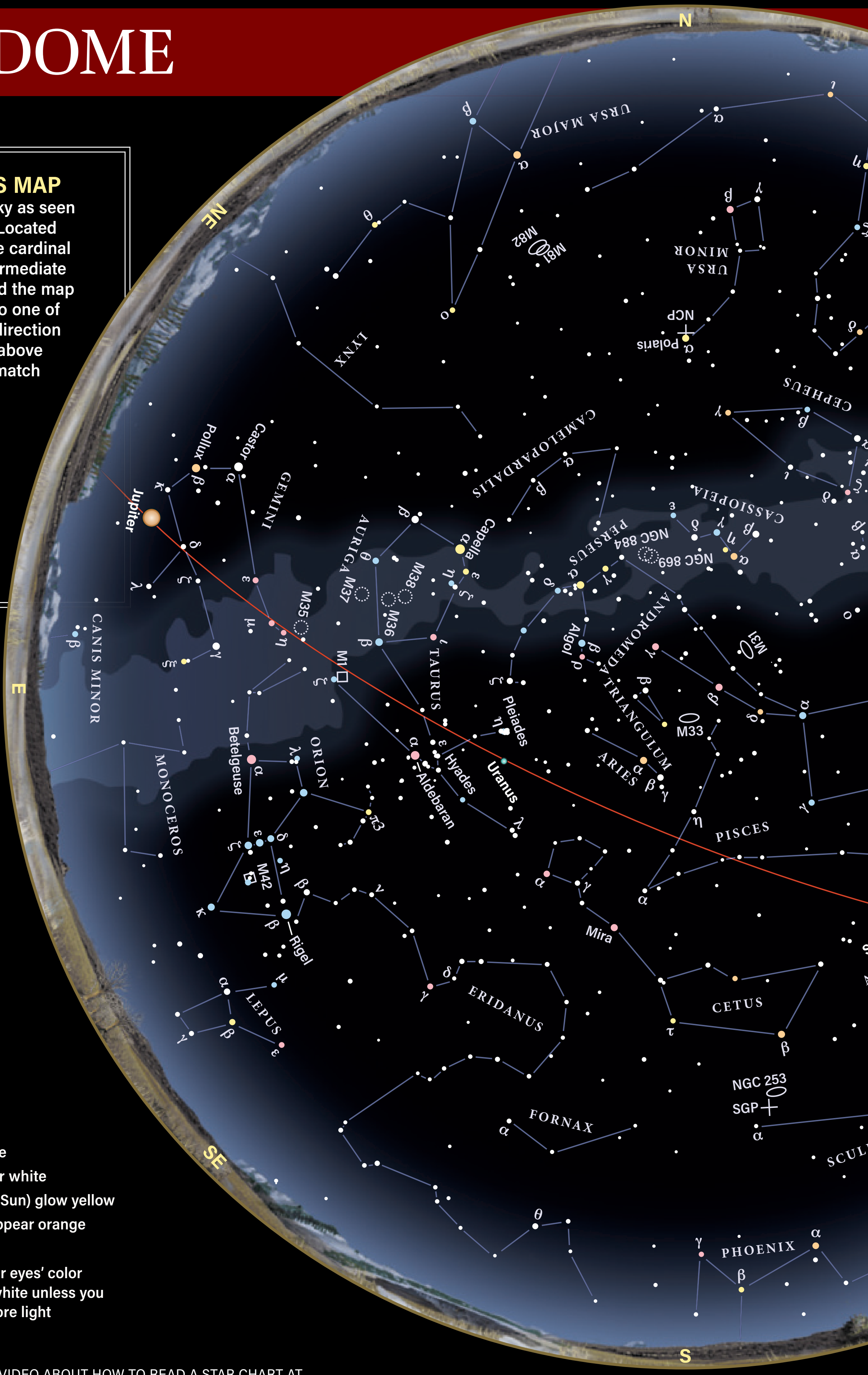
HOW TO USE THIS MAP

This map portrays the sky as seen near 35° north latitude. Located inside the border are the cardinal directions and their intermediate points. To find stars, hold the map overhead and orient it so one of the labels matches the direction you're facing. The stars above the map's horizon now match what's in the sky.

The all-sky map shows how the sky looks at:

9 P.M. December 1
8 P.M. December 15
7 P.M. December 31

Planets are shown at midmonth



N
NE
E
SE
S
URSA MAJOR
M81
M82
URSA MINOR
NCP
Polaris
LYNX
CEPHEUS
CAMELOPARDALIS
CASSIOPEIA
Pollux
Castor
GEMINI
Jupiter
AURIGA
Capella
M37
M38
M36
M35
PERSEUS
NGC 884
NGC 869
ANDROMEDA
Algol
M31
CANIS MINOR
M1
TAURUS
Pleiades
TRIANGULUM
M33
ARIES
Uranus
Hyades
Aldebaran
MONOCEROS
Betelgeuse
ORION
M42
Rigel
PISCES
Mira
ERIDANUS
CETUS
LEPUS
FORNAX
NGC 253
SGP
SCUL
PHOENIX

MAP SYMBOLS

◌ Open cluster

⊕ Globular cluster

☐ Diffuse nebula

⌖ Planetary nebula

⬭ Galaxy

STAR MAGNITUDES

● Sirius

● 0.0 • 3.0

● 1.0 • 4.0

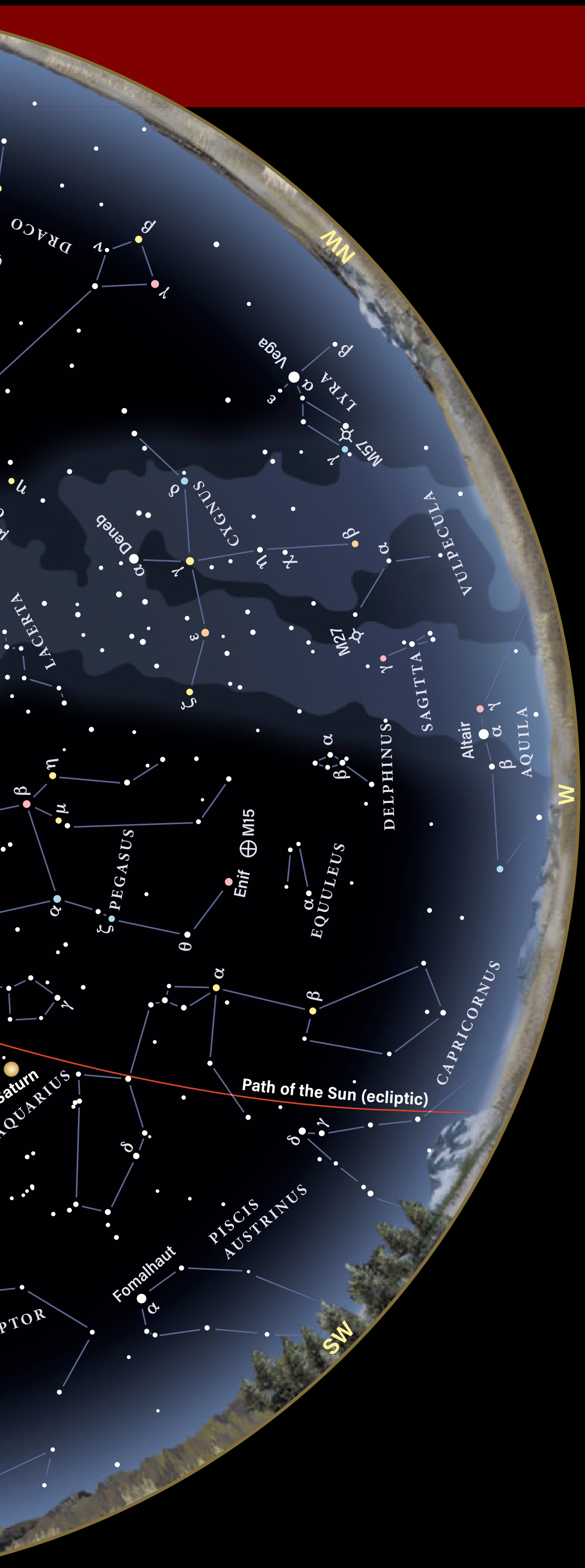
● 2.0 • 5.0

STAR COLORS

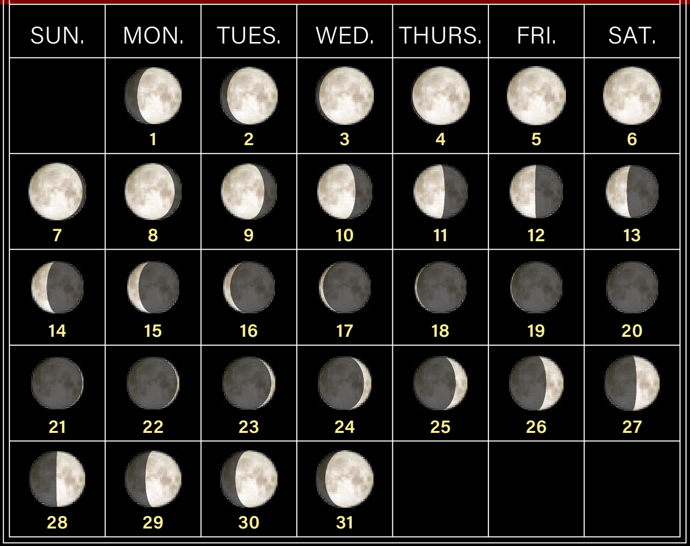
A star's color depends on its surface temperature.

- 🟦 The hottest stars shine blue
- ⬜ Slightly cooler stars appear white
- 🟨 Intermediate stars (like the Sun) glow yellow
- 🟧 Lower-temperature stars appear orange
- 🟥 The coolest stars glow red
- ⬜ Fainter stars can't excite our eyes' color receptors, so they appear white unless you use optical aid to gather more light

BEGINNERS: WATCH A VIDEO ABOUT HOW TO READ A STAR CHART AT **www.Astronomy.com/starchart.**


DRACO
β
ν
γ
NW
Vega
β
α
ε
LYRA
M57
γ
η
δ
CYGNUS
Deneb
α
γ
η
χ
β
α
VULPECULA
LACERTA
ε
ζ
M27
γ
SAGITTA
Altair
γ
α
β
AQUILA
α
β
DELPHINUS
W
η
β
μ
PEGASUS
M15
Enif
EQUULEUS
α
α
ζ
θ
α
β
γ
CAPRICORNUS
Saturn
AQUARIUS
Path of the Sun (ecliptic)
δ
δ
γ
PISCIS AUSTRINUS
Fomalhaut
α
SW
PTOR

DECEMBER 2025



SUN.	MON.	TUES.	WED.	THURS.	FRI.	SAT.
	1	2	3	4	5	6
7	8	9	10	11	12	13
14	15	16	17	18	19	20
21	22	23	24	25	26	27
28	29	30	31			

ILLUSTRATIONS BY *ASTRONOMY*: ROEN KELLY

Note: Moon phases in the calendar vary in size due to the distance from Earth and are shown at 0h Universal Time.

CALENDAR OF EVENTS

3 The Moon passes 5° north of Uranus, 10 P.M. EST

4 The Moon is at perigee (221,806 miles from Earth), 6:07 A.M. EST

Full Moon occurs at 6:14 P.M. EST

7 The Moon passes 4° north of Jupiter, 11 A.M. EST

Mercury is at greatest western elongation (21°), 4 P.M. EST

Asteroid Psyche is at opposition, 9 P.M. EST

10 The Moon passes 0.7° north of Regulus, 2 A.M. EST

Neptune is stationary, 7 P.M. EST

11 Last Quarter Moon occurs at 3:52 P.M. EST

14 Geminid meteor shower peaks

17 Asteroid Juno is in conjunction with the Sun, 1 A.M. EST

The Moon is at apogee (252,477 miles from Earth), 1:09 A.M. EST

18 The Moon passes 6° south of Mercury, 7 A.M. EST

The Moon passes 0.4° south of Antares, 8 A.M. EST

Mercury passes 6° north of Antares, 4 P.M. EST

19 New Moon occurs at 8:43 P.M. EST

21 Winter solstice occurs at 10:03 A.M. EST

22 The Moon passes 0.6° north of Pluto, 4 P.M. EST

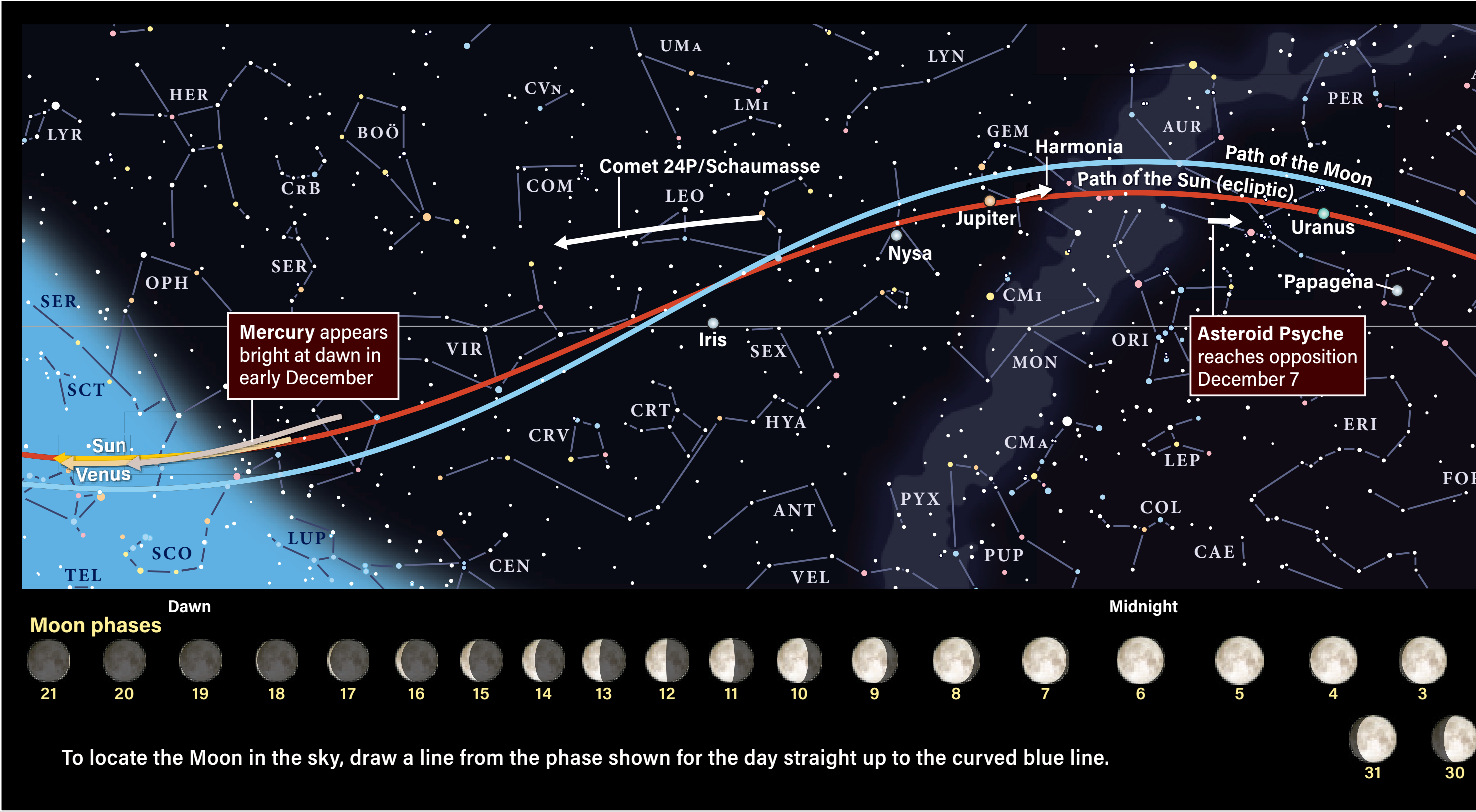
26 The Moon passes 4° north of Saturn, 11 P.M. EST

27 The Moon passes 3° north of Neptune, 4 A.M. EST

First Quarter Moon occurs at 2:10 P.M. EST

31 The Moon passes 5° north of Uranus, 7 A.M. EST

PATHS OF THE PLANETS


LYR
HER
BOÖ
CRB
SER
OPH
SER
SCT
Sun
Venus
SCO
TEL
LUP
CVN
COM
UMA
LMI
LEO
Comet 24P/Schaumasse
VIR
Iris
SEX
CRV
CRT
HYA
ANT
CEN
VEL
LYN
GEM
Harmonia
Jupiter
Nysa
CMI
MON
CMA
PYX
PUP
AUR
Path of the Moon
Path of the Sun (ecliptic)
Uranus
Papagena
PER
ORI
LEP
COL
CAE
ERI
FOR
Dawn
Midnight
Moon phases
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
31
30

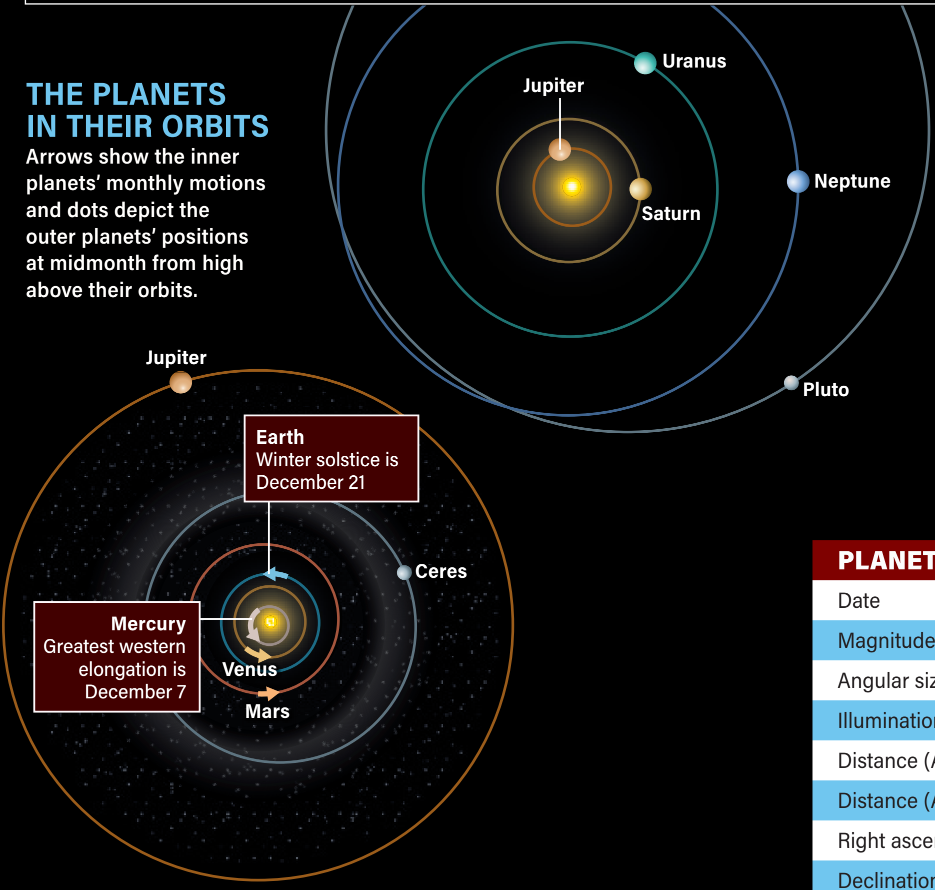
Mercury appears bright at dawn in early December

Asteroid Psyche reaches opposition December 7

To locate the Moon in the sky, draw a line from the phase shown for the day straight up to the curved blue line.

THE PLANETS IN THEIR ORBITS

Arrows show the inner planets' monthly motions and dots depict the outer planets' positions at midmonth from high above their orbits.

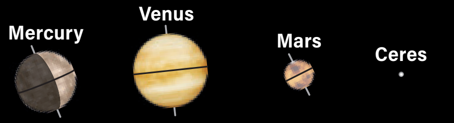

Uranus
Jupiter
Saturn
Neptune
Pluto
Jupiter
Ceres
Venus
Mars

Earth
Winter solstice is December 21

Mercury
Greatest western elongation is December 7

THE PLANETS IN THE SKY

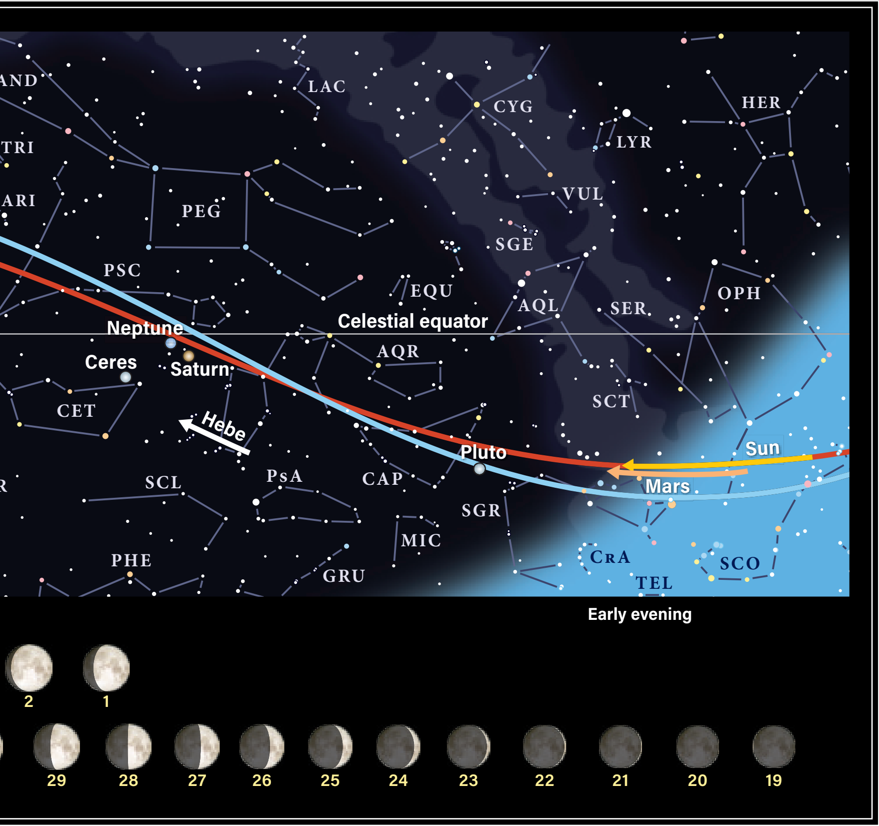
These illustrations show the size, phase, and orientation of each planet and the two brightest dwarf planets at 0h UT for the dates in the data table at bottom. South is at the top to match the view through a telescope.


Mercury
Venus
Mars
Ceres

PLANETS	MERCURY	VENUS
Date	Dec. 1	Dec. 15
Magnitude	0.1	–3.9
Angular size	8.0"	9.8"
Illumination	36%	100%
Distance (AU) from Earth	0.843	1.700
Distance (AU) from Sun	0.324	0.726
Right ascension (2000.0)	15h15.1m	17h05.5m
Declination (2000.0)	–15°22'	–22°41'

This map unfolds the entire night sky from sunset (at right) until sunrise (at left). Arrows and colored dots show motions and locations of solar system objects during the month.

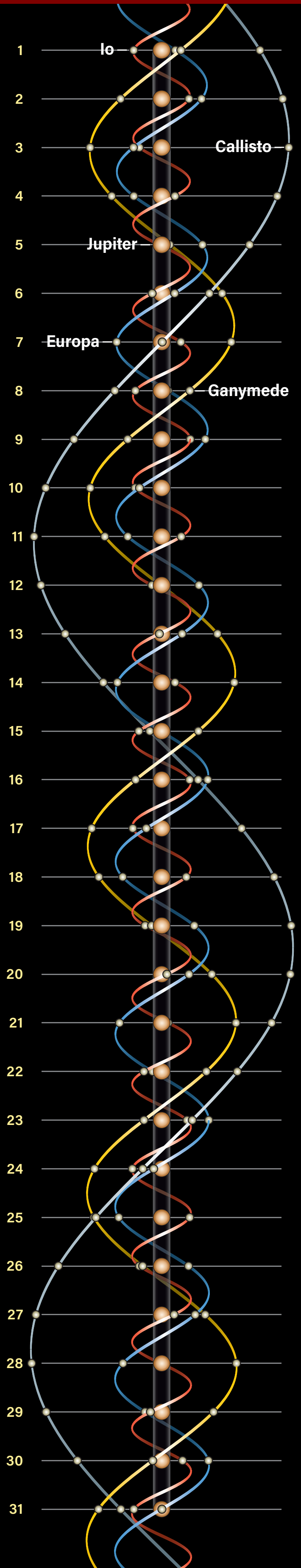
DECEMBER 2025

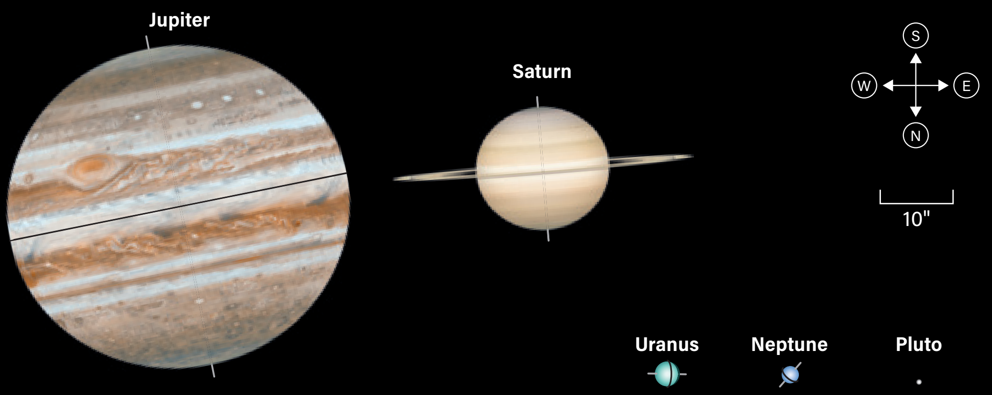

AND
LAC
CYG
HER
LYR
TRI
ARI
PEG
VUL
SGE
PSC
EQU
AQL
SER.
OPH
Neptune
Celestial equator
Ceres
Saturn
AQR
CET
Hebe
SCT
Sun
Pluto
Mars
SCL
PsA
CAP
SGR
MIC
CrA
SCO
PHE
TEL
GRU
Early evening
2
1
29
28
27
26
25
24
23
22
21
20
19

Callisto
Europa
Io
Ganymede

JUPITER'S MOONS

Dots display positions of Galilean satellites at 11 P.M. EST on the date shown. South is at the top to match the view through a telescope.




Jupiter
Saturn
S
W
E
N
10"
Uranus
Neptune
Pluto

MARS	CERES	JUPITER	SATURN	URANUS	NEPTUNE	PLUTO
Dec. 15	Dec. 15	Dec. 15	Dec. 15	Dec. 15	Dec. 15	Dec. 15
1.2	8.7	–2.6	1.0	5.6	7.7	15.3
3.9"	0.5"	45.5"	17.6"	3.8"	2.3"	0.1"
100%	97%	100%	100%	100%	100%	100%
2.421	2.549	4.331	9.436	18.595	29.764	36.168
1.447	2.898	5.206	9.524	19.493	29.885	35.410
17h57.4m	0h29.9m	7h39.5m	23h45.5m	3h43.7m	23h58.5m	20h20.2m
–24°13'	–7°27'	21°40'	–4°06'	19°33'	–1°37'	–23°24'

— *Continued from page 29*

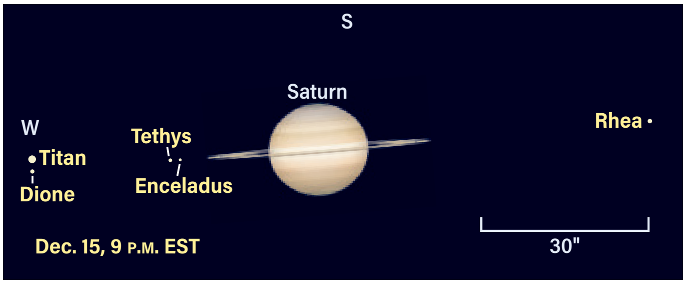
WHEN TO VIEW THE PLANETS

EVENING SKY
Jupiter (east)
Saturn (south)
Uranus (east)
Neptune (south)

MIDNIGHT
Jupiter (east)
Saturn (west)
Uranus (southwest)
Neptune (west)

MORNING SKY
Mercury (southeast)
Jupiter (west)
Uranus (west)

Double vision



Dione stands due north of Titan the evening of Dec. 15. The pair will be close to the resolution limit of small scopes — can you separate the two moons?

east of 14 Tau. By Dec. 13, Uranus is 7' due south of 14 Tau. By the 24th it's moved farther west and is 14" due south of 13 Tau. By year's end, Uranus stands 21" southwest of 13 Tau and appears to have an 8th-magnitude companion, a field star. Through a telescope, Uranus reveals a pale greenish disk spanning 4".

A nearly Full Moon crosses in front of the Pleiades Dec. 3, heralding multiple occultations of its bright stars. While the stars do disappear at the dark limb, only brighter members of the cluster will be visible thanks to the blazing Moon, and even they will be a challenge.

Magnitude 3.7 Electra is the first major Pleiad to disappear, soon after 7 P.M. CST from Chicago. The timing varies by location, but the Moon crosses the cluster between about 7 P.M. and 9:30 P.M. CST. Use high magnification on your telescope, which will remove as much of the Moon from your field of view as possible.

Jupiter rises about 8 P.M. local time Dec. 1 and a little over two hours earlier by the 31st. It's a spectacular object, passing more than 70° high around local midnight, dominating the stars of Gemini. Just one month from opposition in January, Jupiter reaches magnitude –2.7 by month's end. The disk spans 44" at the start of December and grows to 46" by the New Year. A waning gibbous Moon stands 8° northwest of Jupiter the evening of Dec. 6.

A full rotation of the planet (less than 10 hours) is visible in a single night. Jupiter's fast rotation causes atmospheric features to move noticeably across the disk in 10 to 15 minutes. There is a treasure trove of delicate cloud features to follow. High-speed video capture at regular intervals of a few minutes can produce a time-lapse of Jupiter's rotation, recording brief moments of good seeing.

The four Galilean moons are bright enough to see in any telescope, and even in tripod-mounted binoculars. As they orbit they cross in front of the planet and cast shadows, as well as hide behind Jupiter in occultations.

On Dec. 1/2, after midnight for the eastern half of the U.S., Ganymede casts its shadow across the planet's face beginning around 1:07 A.M. EST. The shadow is so large that it takes about 10 minutes to fully appear. Three hours later, at 4:18 A.M. EST, the shadow begins to leave the western limb, just as Ganymede itself approaches the eastern side. Ganymede's transit begins at 4:44 A.M. EST. It takes more than three hours to cross the disk, leaving as dawn begins in the Mountain Time Zone.

Io approaches the eastern limb of the gas giant Dec. 4/5, the moon's shadow appearing at 12:19 A.M. EST (the 5th in EST only). Io joins 49 minutes later,

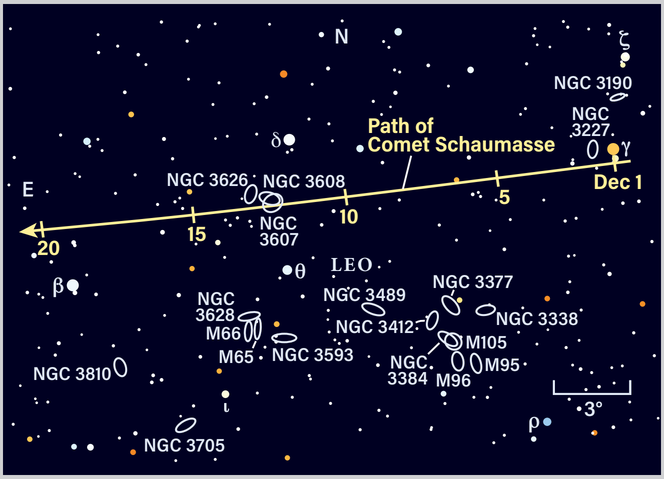
COMET SEARCH | Not what you expected?

COMET 24P/SCHAUMASSE rises around midnight, making it worthwhile to stay up late, especially on the weekend of the Geminids. On Friday the 12th, it shares a low-power field with NGC 3607 and 3608 (10th and 11th magnitude, respectively). With Schaumasse forecast at 9th to 12th magnitude, you can estimate its brightness easily. Use detailed charts to make sure you're not misidentifying a background galaxy!

Somewhat hampered by moonlight will be the "tilting knife" effect from Dec. 7–11. This is when Earth passes through the plane of the comet's elliptical orbit, giving us an edge-on view of the dust fan. Any blue ion tail remains out of sight behind it.

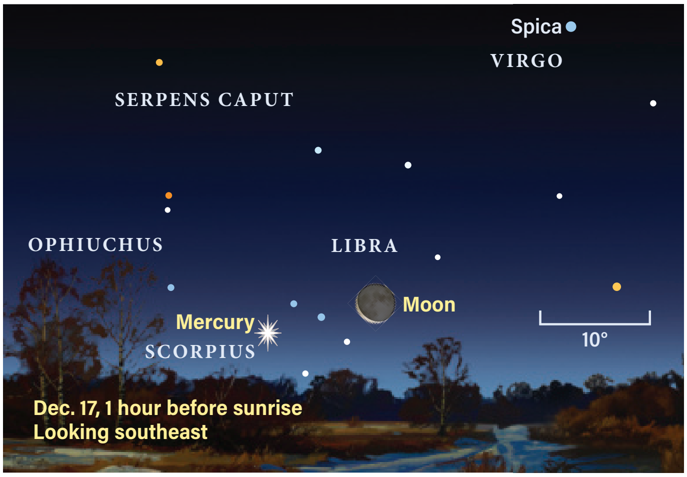
From country skies on the 25th, the comet is on the south side of M100 in a high-power field. Integrated magnitude can be misleading, as M100 is a large face-on spiral that is diffuse, whereas Schaumasse is compact. Compare their forms, too — the comet will have a sharply defined southeast flank where the solar wind pushes back dust. The fan-shaped tail is still steeply tilted away, and imagers should get that classic green glow around the head.

Comet 24P/Schaumasse



Comet Schaumasse is moving quickly through the sky. This chart shows its path in the first half of December. Galaxies are shown down to magnitude 11. Visit Astronomy.com for a chart depicting the rest of the month, included in the online version of this story.

A lovely predawn scene



Dec. 17, 1 hour before sunrise
Looking southeast

The thin crescent Moon, lit by earthshine, joins bright Mercury in the morning sky before dawn Dec. 17.

following until the shadow leaves at 2:34 A.M. EST. Io departs 50 minutes later. The sequence repeats later in the month with Io and its shadow closer together, as we are approaching opposition.

On Dec. 20, Io's shadow appears at 10:35 P.M. EST and the moon follows 30 minutes later. Both cross the disk in just over two hours. On Dec. 27/28, shadow ingress is at 12:28 A.M. EST (the 28th in EST only) and Io follows 20 minutes later. At opposition next month, the time difference drops to zero.

On Dec. 6/7, Europa's shadow appears at 11:54 P.M. EST, leaving just under three hours later. The moon follows, transiting from 1:31 A.M. EST (Dec. 7 in the eastern U.S.) through 4:22 A.M. EST.

Callisto transits on the evening of the 7th, beginning at 9:17 P.M. EST and ending four hours later.

Try to spot Ganymede's reappearance Dec. 12/13 around 1 A.M. EST (the 13th in the eastern U.S.). How early do you spot the small bulge at the northeastern limb of Jupiter? Ganymede takes about seven minutes to fully reappear from behind the disk.

The year ends with a transit of Europa and its shadow. The shadow is first at 9:01 P.M. EST, followed by the moon 28 minutes later. The transit takes nearly three hours, ending shortly before the New Year rolls into the Central Time Zone.

Mercury is now at its best for the year in the morning sky for Northern Hemisphere observers. On the 1st it rises around 5:30 A.M. local time, some 90 minutes before sunrise. It quickly achieves greatest elongation west of the Sun Dec. 7. On that day, Mercury stands 30° southeast of 1st-magnitude Spica. The star is visible about 30° high in the southeast at 6:30 A.M. local time, with Mercury 10° high.

The small planet starts December at magnitude 0.1 and reaches magnitude –0.5 by the 10th, remaining that way for nearly three weeks before brightening even more. There's an attractive scene on the 17th as a thin waning crescent Moon joins Mercury; the two are 10° apart. By 6:45 A.M. local time, they are 9° high. As the sky brightens, be on the lookout for Antares in Scorpius, which rises shortly before 6:30 A.M. and sits 6.5° below Mercury.

The Moon slides to sit 1° below Antares on the 18th and rises 55 minutes before sunrise, a nice challenge for those with a clear eastern horizon. Look for Mercury, which should be easy. The Moon and Antares lie below and slightly to the right of the planet. By Dec. 28, Mercury is magnitude –0.6 but it is only visible in a bright twilit sky, rising an hour before the Sun. See if you can follow Mercury into the morning on New Year's Eve, when it stands less than 3° high 30 minutes before sunrise — definitely a challenge.

Venus and **Mars** are both approaching solar conjunction in early January and are not visible this month.

The winter solstice occurs Dec. 21 at 10:03 A.M. EST.

__Martin Ratcliffe__ is a planetarium professional with Evans & Sutherland and enjoys observing from Salt Lake City. __Alister Ling__, who lives in Edmonton, Alberta, is a longtime watcher of the skies.

GET DAILY UPDATES ON YOUR NIGHT SKY AT
www.Astronomy.com/skythisweek.

LOCATING ASTEROIDS

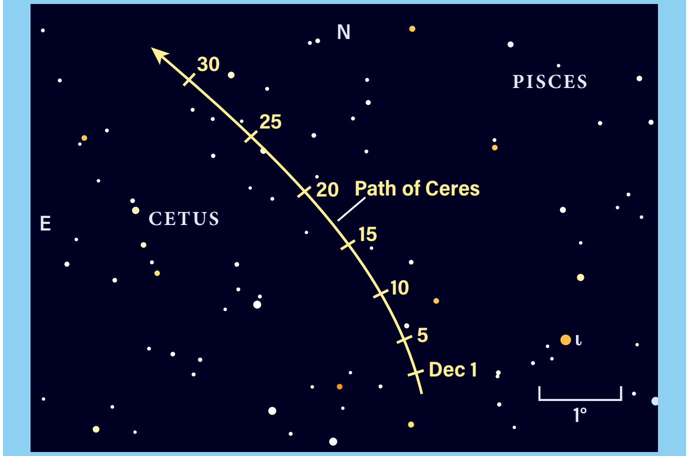
Riding on the back of the Whale

TAKE A STROLL in the (star) fields to follow dwarf planet 1 Ceres. Fading from magnitude 8.5 to 8.9, the 600-mile-wide world won't be a walk in the park, yet still easy enough from the suburbs with a 3-inch scope. You might want to start just east of Saturn and nail Neptune (magnitude 7.7) to calibrate your expectations.

Gazers without motors can let Earth do the "hopping" in the first week of December. Center on magnitude 3.6 Iota (ι) Ceti, then come back eight minutes later to find Ceres sharing the field with a slightly brighter field star. Right through the 23rd, the background stars are fainter, with a reversal on the 24th when Ceres becomes component "B" of a double.

New to charts and scopes? It's best to make a quick sketch in a logbook by jotting down four or five stars in a 1° (low-power) field. Come back the next clear night to see which one has moved. If nothing has changed, then you found the wrong field. Just try again — a bit of humble pie is normal.

A leisurely path



Ceres remains close to Iota Ceti all month, tracing out a path that should be relatively easy to follow.

Spot an ASTEROID tonight

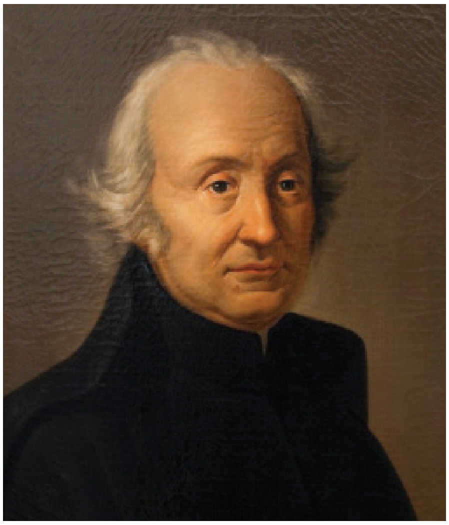
Seen the Messiers, Caldwells, and NGCs? There's another class of objects waiting.

BY GLENN CHAPLE

IF YOU WERE TO ASK a group of dedicated amateur astronomers to list their favorite telescopic targets, few if any would mention asteroids. That's easy to understand. The typical asteroid lacks the jaw-dropping visual impact of the Moon or Saturn. Through the eyepiece, an asteroid is an ordinary-looking stellar speck. In fact, the word asteroid comes from the Greek word *asteroeides*, which means "starlike."

My interest in observing asteroids began in the summer of 1971 when I came across information in an astronomy magazine about the then-visible asteroid 4 Vesta. Using the accompanying finder chart, I spotted Vesta with a handheld 6x refractor. A few months later, another featured asteroid led me to 8 Flora, which I spotted using a 3-inch f/10 reflecting telescope (Edmund Scientific's classic Space Conqueror). That observation evolved into a lifelong quest to notch as many asteroids as possible with that scope. To date, the Space Conqueror has lived up to its name by finding more than 120, including the first 33 discovered and 64 of the first 100.

◀ On Feb. 27, 2020, NASA's OSIRIS-REx spacecraft captured this image of asteroid 101955 Bennu. NASA/GODDARD/UNIVERSITY OF ARIZONA



▶ Italian astronomer Giuseppe Piazzi discovered the first asteroid, 1 Ceres, on Jan. 1, 1801. This oil on canvas painting of him was made in 1825, the year before he died. COSTANZO ANGELINI/INAF/WIKIMEDIA COMMONS

More recently, I've upped my game a notch by adding near-Earth asteroids (NEAs) to the mix. Because they're small, usually less than a few hundred yards in diameter and therefore relatively faint, I chase them with a 10-inch f/5 reflector.

Despite their visual shortcomings, asteroids rank near the top of my favorite celestial objects. Stay with me, and I'll explain why you should add them to your observing repertoire, whether you're a novice or a seasoned observer.

Asteroids 101

First, let's get up to speed on these objects. *Webster's Dictionary* defines an asteroid as a small, rocky celestial body that orbits the Sun, particularly between the orbits of Mars and Jupiter. The terms *asteroid* and *minor planet* are often interchanged. However, minor planets exist throughout the solar system. Asteroids are those minor planets that inhabit the inner solar system and have a rockier composition than their icy outer solar system cousins, the largest of which are called dwarf planets.

Asteroids that orbit the Sun between Mars and Jupiter are known as main-belt asteroids. These are the remnants of a planet that failed to form between the two, thanks to Jupiter's gravitational influence. Millions inhabit this so-called asteroid belt, ranging in size from Vesta, whose diameter is 326 miles (525 kilometers), to bodies less than 3 feet (1 meter) across. Throw in bodies with diameters less than 3 feet, technically defined as meteoroids, and the population might number in the trillions. Despite these numbers, the asteroid belt is relatively barren — not the jumble of space rocks the *Millennium Falcon* had to dodge in *The Empire Strikes Back*.

If you've watched doomsday movies about asteroids striking Earth, you know that not all are safely ensconced in the asteroid belt. Asteroids are found throughout the inner solar system, and a frighteningly large subset of them, the NEAs, have orbits that approach and even intersect Earth's. NEAs are believed to have been pushed sunward out of the asteroid belt either through gravitational interactions with Jupiter or through collisions with other asteroids. As of mid-2025, the International Astronomical Union (IAU) says that more than 38,800 NEAs had been discovered. By year's end, that number may well exceed 40,000. Two-thirds of these actually cross Earth's orbit, and of these more than 2,300 get close enough (within 20 lunar distances) and are large enough (300 feet [91 m] or more) to be considered potentially hazardous asteroids (PHAs).

▲ The author poses with the two telescopes through which he's seen a large number of asteroids. The red telescope is Edmund Scientific's Space Conqueror, a 3-inch f/10 reflector. The larger scope is a 10-inch f/5 reflector. GLENN CHAPLE

The formal identification for an asteroid is a number in parentheses followed by its name, for example, (4179) Toutatis. The parentheses are often omitted — and even the number may be dropped if the asteroid is mentioned more than once in an article. Originally, the number indicated the asteroid's order of discovery, but as more and more asteroids were discovered and then lost, they were given a provisional designation which included the four-digit year of discovery, followed by a letter indicating the half-month of discovery and a second letter indicating the order within that half-month. (There's even an added subscript number if a huge amount of asteroids are discovered during a half-month period, but that's more of an Asteroids 102 topic.) Toutatis' provisional designation was 1989 AC, meaning it was the 3rd asteroid discovered between January 1 and 15, 1989. Only after Toutatis' orbit was well-determined did it get its official number and name.

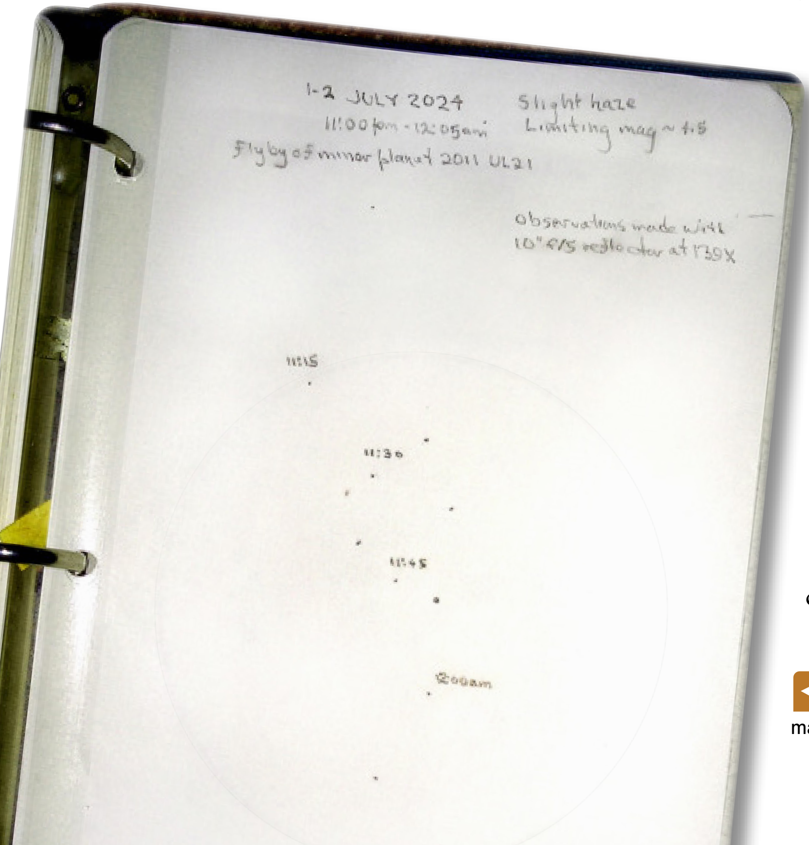
Get started

You can begin your asteroid-seeking odyssey the same way I did, with a bright main-belt asteroid. As my 3-inch reflector proved to me, an expensive, large-aperture telescope isn't necessary. Dozens of asteroids reach magnitude 10.5 or brighter during their oppositions, well within reach of a 2.4-inch refractor. In fact, bright ones like Vesta are within reach of binoculars. For info on the bright, currently-visible asteroid 1 Ceres, turn to page 35. There, you'll find information about Psyche, including a map to help you find it.

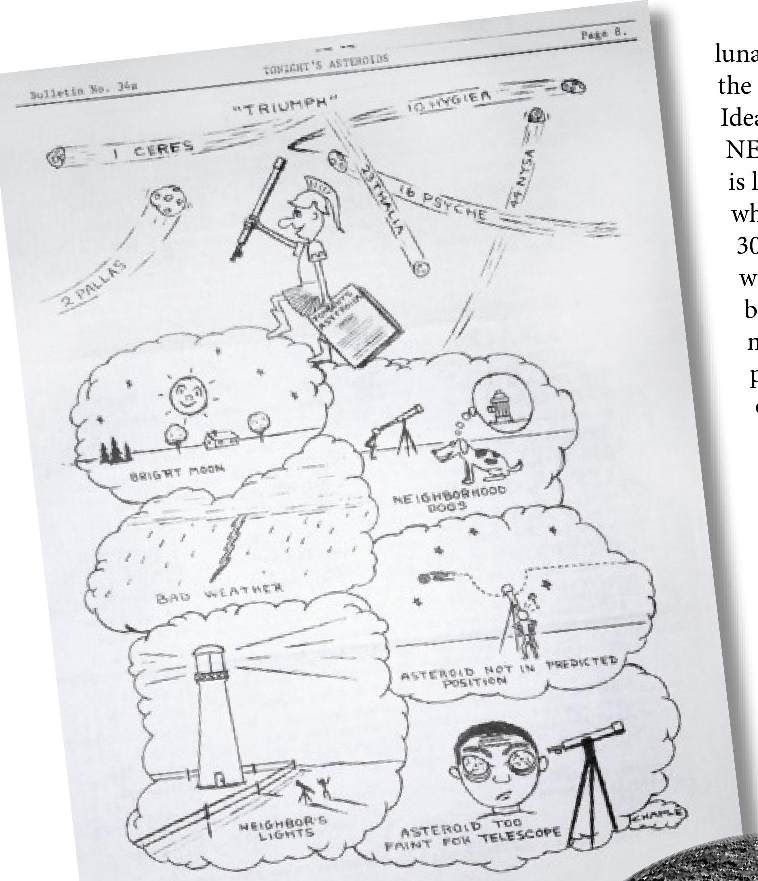
With map in hand, go outside and aim your telescope toward Ceres's predicted position. If you see a starlike object there, congratulations! You've spotted your first asteroid. The sight may not have given you an adrenaline rush, but you have to admit it's a pretty satisfying achievement. If you're like me and want to make sure you've found the "real deal," you may want to observe the asteroid on subsequent evenings. If the starlike speck you saw is no longer there and it now appears in an area of sky that was previously blank, you can be 100 percent sure you've made the observation.

If viewing your first asteroid gives you a thirst for more, you can try again next month with the featured asteroid in the next issue of *Astronomy*. Can't wait? There are several websites that provide information and finder charts on currently visible asteroids. Try astro.vanbuitenen.nl/asteroids, sky-tonight.com/asteroids, or in-the-sky.org/data/asteroids.php.

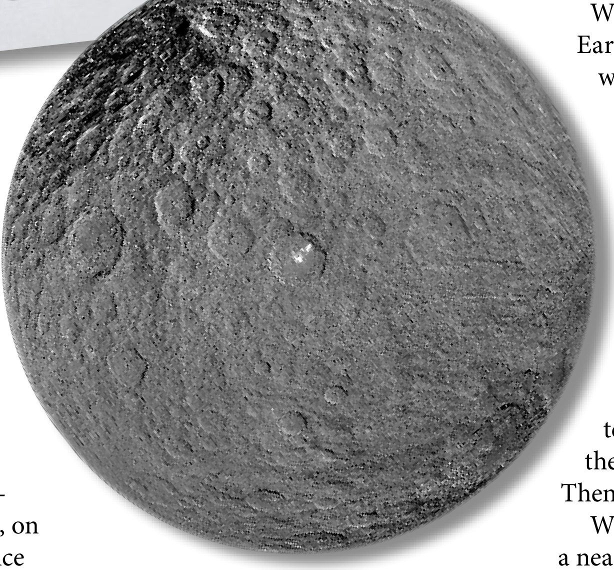
By and large, the asteroids we're talking about so far are main-belters. At their opposition distance, anywhere between 112 million and 205 million miles (180 million and 330 million km), their apparent motion is rather small, perhaps ½°



◀ This sketch from the author's asteroid notebook shows the movement of minor planet 2011 UL21. Note that he recorded the date, time, limiting magnitude, and the telescope/eyepiece combination he used. GLENN CHAPLE



▲ When the author isn't observing asteroids, he's still thinking about them, as this cartoon that he created many years ago shows. GLENN CHAPLE



▶ This image of asteroid (now dwarf planet) 1 Ceres was captured by NASA's Dawn spacecraft May 4, 2015, at a distance of 8,476 miles (13,641 km). NASA/JPL-CALTECH/UCLA/MPS/DLR/IDA/JUSTIN COWART (CC BY 2.0)

(one Moon diameter) in 24 hours. This makes them relatively easy pickings for the novice. The typical NEA, on the other hand, can cover that distance in a single hour or less. These moving targets require a little more experience.

If you're up to chasing down one of the NEAs, start with the spaceweather.com website. Scrolling down, you'll find a section labeled "Near Earth Asteroids," which includes a list of recent and upcoming NEA encounters spanning roughly two months. Despite its closeness, the typical NEA is rather small and faint, best seen with medium- to large-aperture instruments. To find the most reachable NEAs, focus in on two columns: the miss distance, expressed in lunar distances (LDs), and the diameter in meters. Ideally, you'll want an NEA whose miss distance is less than 5 LDs and whose diameter exceeds 300 meters — in other words, one that will be bright enough (14th magnitude or better) to pick out with an 11-inch or larger scope. Be sure to jot down the date of closest approach.

The next step is to find out where in the sky and how bright your target NEA will be. A go-to source for this information is the IAU's Minor Planet and Comet Ephemeris Service (https://minorplanetcenter.net/iau/MPEph/MPEph.html). In the appropriate spaces, type in the asteroid's identity (for most NEAs, the discovery nomenclature), an ephemeris start date (I suggest one day before close approach), and request its hourly coordinates over a 48-hour period. Using these coordinates, trace the asteroid's path on a star atlas, looking for instances when it passes a bright star or distinguishable asterism. Finally, I tailor-make and print out a chart using the American Association of Variable Stars Variable Star Plotter (https://apps.aavso.org/vsp — check it out, it's a neat and free tool) on which I plot the asteroid's locations from an hour before until an hour after its encounter with the star or asterism. It's important that my chart include stars up to a magnitude fainter than the asteroid.

What to expect

To describe what happens next, let me put you at the eyepiece as the NEA makes its appearance. You're gazing at the asterism you chose as an ambush site. It's still a few minutes away from the time of the asteroid's predicted passage. You see nothing yet. The minutes pass. Still nothing! Could the predictions have been off? Then you spot it at the edge of the eyepiece field — a stellar speck moving slowly towards the asterism. You realize that this innocent-looking speck is in reality an asteroid the size of a battleship passing 4 LDs (about a million miles) from Earth at a speed of several miles per second.

Were it to drift directly across the Earth's orbital path at that distance, it would miss us by a matter of hours. An impact on land would create a crater more than 2 miles (3.2 km) across and cause millions of casualties if it struck a populated area. A hit in the ocean would generate tsunamis hundreds of feet high, creating an even greater loss of life in coastal communities. Regardless of where it hit, the asteroid would affect weather patterns on a global scale. Eye glued to the eyepiece, you take a deep breath. Then it passes, and all is well.

Whenever it has been announced that a near-Earth asteroid will make a close pass, I check to see if it's included in the database of the planetarium software I use, Sky Safari Pro. If it is, I center the object, then let time pass, watching for easy-to-find and easy-to-identify asterisms along its path. Then, I locate the asterism in my eyepiece and wait for the asteroid to come to me. I have found this to be a successful method for spotting these faint space rocks. Good luck!

Glenn Chaple *is a contributing editor of* Astronomy *who has tracked down celestial objects large and small for many years.*

Stars lost to

Algol
Almaach
Caput Medusæ
HEAD OF MEDUSA
Triangula
THE TRIANGLES
R.27.D.32
R.22.D.27
Musca
THE FLY
R.40.D.28
Arietis or El Nath
Sheratan
Mesarthim
Aries
THE RAM
R.30.D.12
ZODIAC
Menkar
Piscis Borealis
THE NORTHERN FISH
Mirach
Delta
Alpheratz
ANDROMEDA
R.14.D.30
EQUINOCTIAL COLURE
Gloria Frederica
FREDERICKS GLORY
The Square of Pegasus
The Pisces
FISHES
R.5.D.10
Algenib
THE EARTHS ORBIT

"Bright star, would I were steadfast as thou art." — John Keats

Star maps and charts are a mainstay of both amateur and professional sky observers. Whether it's on a simple seasonal map or in a comprehensive atlas, the stars listed appear steadfast and constant.

Yet there are stars that have appeared in these publications and then vanished. Some have been misplaced or even just imagined. Understanding how stars can be lost — and sometimes found — is like reading an intriguing mystery.

Nova stella

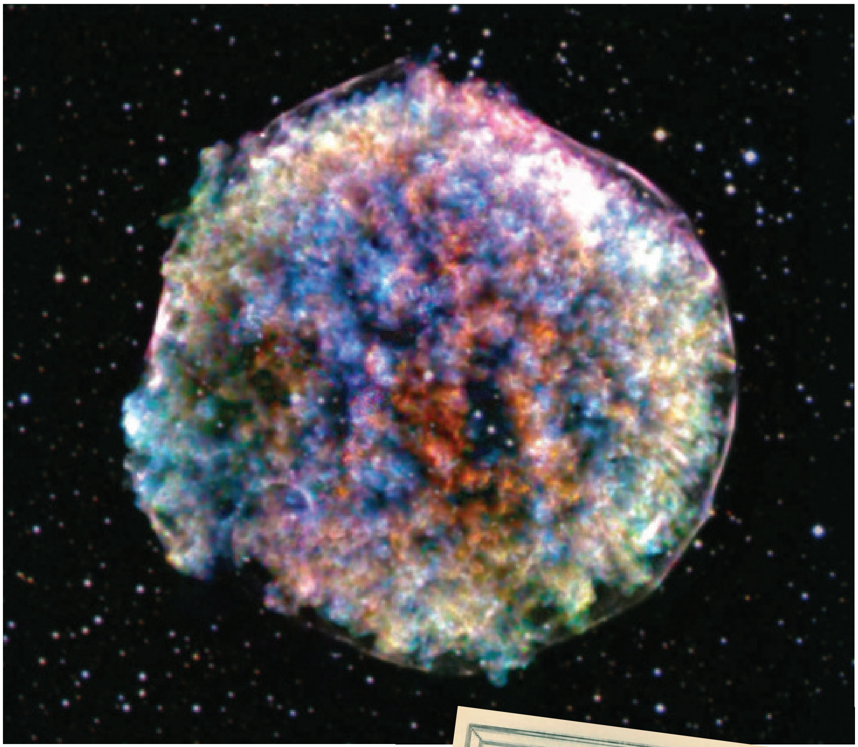
On a cold November night in 1572, the young astronomer Tycho Brahe was walking home. It had been cloudy for a few nights but was now clear. Tycho knew the stars well and was scanning the sky when he saw a star in the constellation Cassiopeia that he had not seen there before. Tycho had been raised and educated in Aristotelian, geocentric cosmology. The Church taught that the universe was eternal and unchanging. So how could a new star appear in the heavens?

Tycho and other astronomers carefully measured the position of the new star. In 1573, he published a book titled *De Nova Stella*, extolling his observations and ideas about this astounding star. He included a star map of Cassiopeia denoting the nova with the letter *I*. Observations from across Europe helped to determine that the new star was in a sphere well beyond the Moon, shaking the foundations of astronomy.

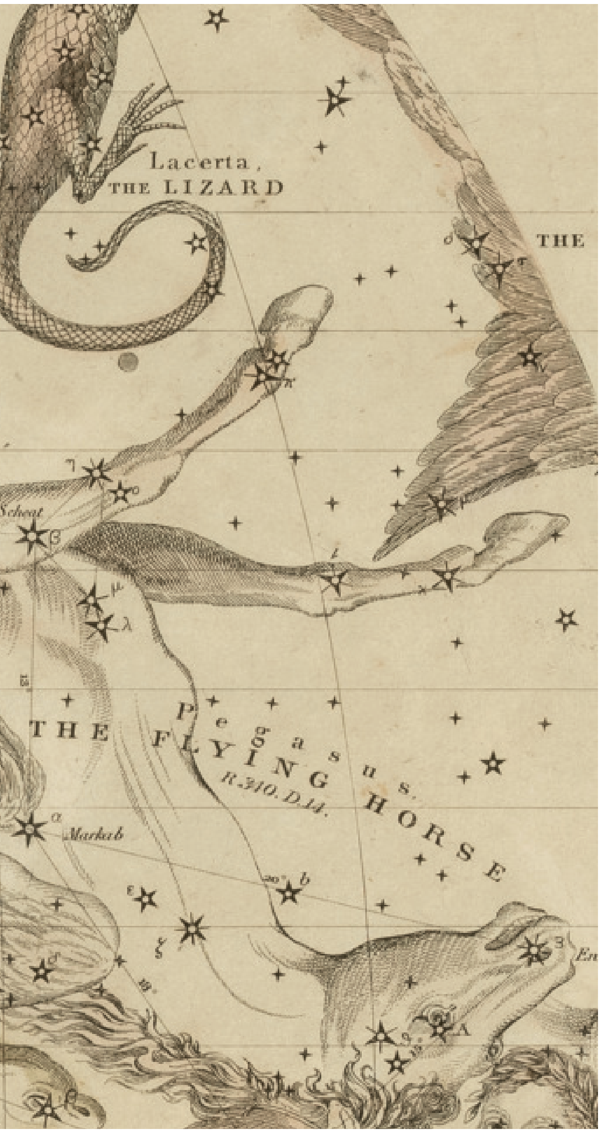
history

There's a long list of celestial lights that have gone missing.

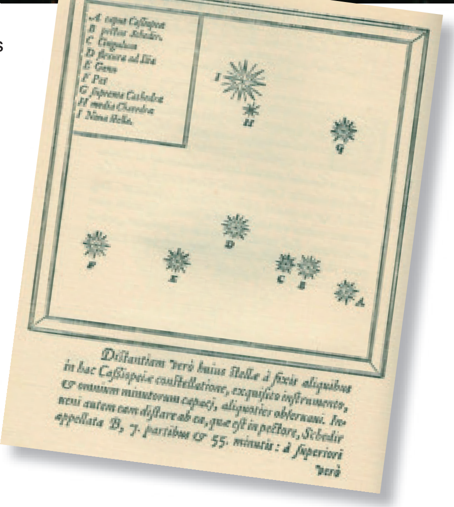
BY RAYMOND SHUBINSKI



This image of Tycho's supernova combines data from NASA's Chandra X-ray Observatory and the Digital Sky Survey. X-RAY: NASA/CXC/RIKEN & GSFC/T. SATO ET AL; OPTICAL: DSS



This 1835 star map by Elijah Hinsdale Burritt shows two "lost" constellations. Musca (later called Musca Borealis to distinguish it from the current Southern Hemisphere constellation) is on the far left, and Gloria Frederica lies at top center. MICHAEL E. BAKICH



A caput Caſsiopeæ
B pectus Schedir.
C Cingulum
D flexura ad Ilia
E Genu
F Pes
G ſuprema Cathedræ
H media Cathedræ
I Noua ſtella.

Diſtantiam verò huius ſtellæ à fixis aliquibus
in hac Caßiopeiæ conſtellatione, exquiſito inſtrumento,
& omnium minutorum capaci, aliquoties obſeruaui. In-
ueni autem eam diſtare ab ea, quæ eſt in pectore, Schedir
appellata B, 7. partibus & 55. minutis: à ſuperiori
verò

The largest star at the top, labeled I, indicates where Tycho Brahe noted the position of the supernova of 1572 on this chart. TYCHO BRAHE/WIKIMEDIA COMMONS

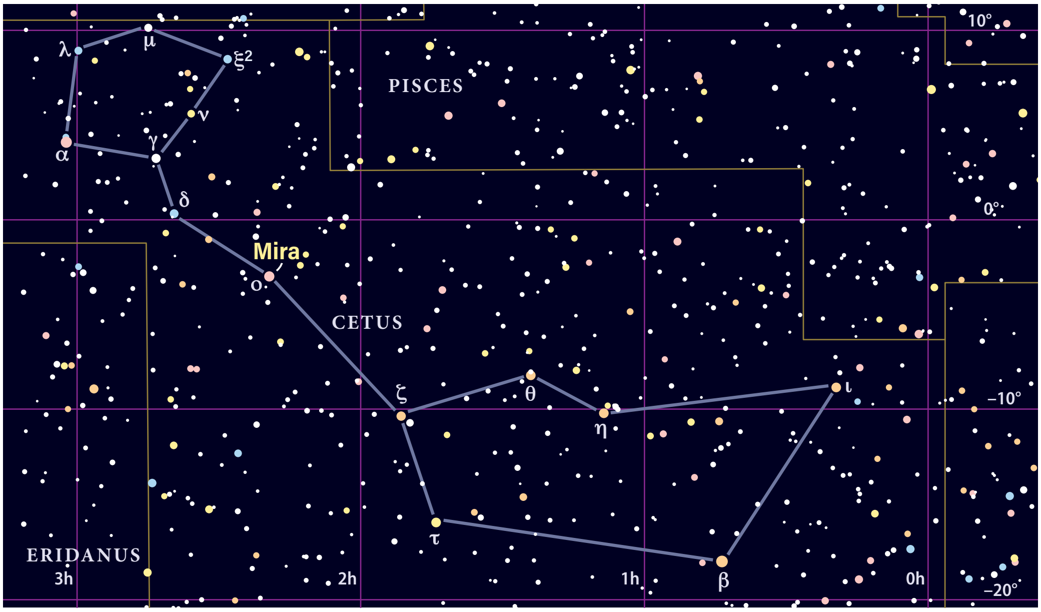
By 1574, Tycho's star had faded from view and was seemingly lost forever. But 32 years later a similar story played out all over again. In the autumn of 1604, Johannes Kepler, astronomer and astrologer to Emperor Rudolph II, was awakened in the middle of the night to a story of a new star glimpsed through the cloudy skies of Prague. By Oct. 17, the clouds were gone and Kepler saw the new star shining brightly in the constellation Ophiuchus. Kepler was not the first to see this new star, but his observations and ideas would be significant. Tycho Brahe had achieved fame with his star, and now Kepler had his chance.

Visible low in the southwest, the star appeared just above Jupiter. Mars and Saturn were also part of the celestial show. In his 1606 book *De Stella Nova in Pede Serpentarii*, Kepler supported the idea that his new star was also far beyond the Moon. As with Tycho's star, this apparition faded from view and was lost to observers. We now know that both new stars were type I supernovae.

Celestial confusion

Looking like diamonds in the sky, the Pleiades (M45) are perched on the back of Taurus the Bull. This cluster has one of the longest histories of documentation of any star group. Its brightest stars are regarded as seven sisters or maidens in many cultures.

According to Greek myth, these stars represent the seven daughters (Alcyone, Asterope, Celaeno, Electra,



↑ Mira (Omicron Ceti) is a star that has disappeared and reappeared many times throughout history. *ASTRONOMY*/RICHARD TALCOTT AND ROEN KELLY

← Could one of these stars in the Pleiades (M45) be the so-called "Lost Pleiad"? The mystery of the missing sister is a tough one to solve. CHRIS SCHUR

Maia, Merope, and Taygeta) of Atlas and Pleione, all of whom have named stars in the cluster. On a clear moonless night, the unaided eye can perceive stars as faint as 6th or 7th magnitude. The brightest Pleiads range from about 3rd magnitude to the edge of visibility at 6th magnitude. Most people can see at least six, but not everyone can easily see all seven, leading to myths worldwide about the "lost Pleiad."

But which Pleiad is the elusive one? Three have been suggested. Electra looms large in stories of Troy and its destruction. Legends say that as the city burned, she covered her face with a veil, making it difficult to see her. At magnitude 3.7, however, her star is fairly easy to spot in a dark sky.

Merope is most often associated with the lost Pleiad. She shamed her parents by marrying a mortal and then hid herself in shame. However, like Electra, Merope's star should be visible without much effort at magnitude 4.2.

Pleione, the girls' mother, may actually be the best candidate. To see this star, you need a truly dark sky and sharp eyes. Pleione can be hard to spot because it is nestled only 5' from Atlas. Pleione is also a variable star, ranging from magnitude 4.7 to 5.5. Could this be the missing star? The mystery may never be solved.

Cosmic hide and seek

Some stars like to play peek-a-boo. One of the most famous is the variable star Mira (Omicron [ο] Ceti) in Cetus the Whale. Mira is a pulsating variable star that fluctuates between 2nd and 10th magnitude. Its variable nature was discovered by David Fabricius in August 1596. He chose Omicron in Cetus as a reference star to help track what he thought was the planet Mercury.

At the beginning of the month, the star was about 3rd magnitude but in a matter of weeks, it increased to 2nd magnitude. Over the next few months, the star faded and disappeared and was lost from view. The invention of the telescope was still more than a decade away, so Fabricius had no way of observing the star at its faintest.

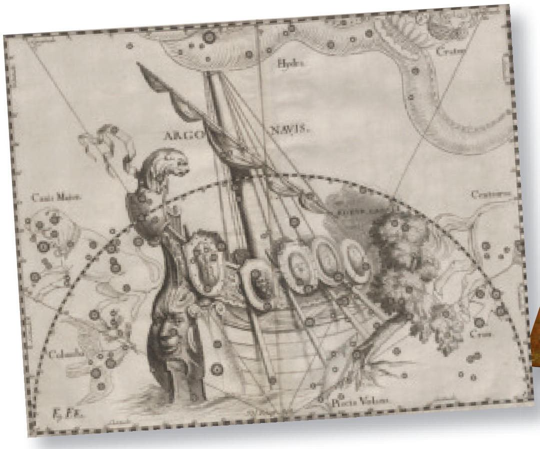
The 17th-century astronomer Johannes Hevelius worked out the star's 11-month cycle and named it Mira, which means "wonderful." We now know that Mira is a 6-billion-year-old red giant star nearing the end of its life. Other Mira-type stars can be followed through their disappearing acts. Chi (χ) Cygni pulsates from an easily visible magnitude 3.3 to an incredibly faint 14th magnitude. Not far from Regulus (Alpha [α] Leonis) is another red giant, R Leonis, that swings between 4th and nearly 12th magnitude every 312 days.

Until astronomers came to grips with the physics of stellar evolution and understood what powers such stars' cycles of variability, these stars were truly lost and found again and again.

Cosmic confusion

A star doesn't need to disappear to confuse astronomers, however. Sometimes, recording and naming celestial objects can create problems. For example, Charles Messier's famous catalog of 109 "fuzzy" objects contains a few mysteries. Today, M47 in the constellation Puppis is listed as a galactic star cluster. Messier described it as a fairly bright cluster not far from M46. However, using Messier's coordinates to search for this object reveals no cluster at all — it seems to have been lost.

In the late 19th century, the astronomer J.L.E. Dreyer began to sort out the astronomical catalogs compiled by Messier, William Herschel, Lord Rosse, and others. It



The defunct constellation Robur Carolinum (Charles' Oak) appears at the bottom right of this star map published in 1690 by Johannes Hevelius. JAN HEWELIUSZ/WIKIMEDIA COMMONS

Johannes Kepler plotted the position (labeled N) of the supernova of 1604 on this star map from his *De Stella Nova*. JOHANNES KEPLER/WIKIMEDIA COMMONS

must have been a daunting task. Dreyer assigned a star cluster very close to M46 as NGC 2478. Messier, or those who copied his catalog for publication, may have provided faulty coordinates; NGC 2478 is now assumed to be what Messier originally observed. Dryer's original *New General Catalogue* contained nearly 8,000 objects, but it also incorporated duplications and errors made by past observers. *The Revised NGC Catalogue* has been corrected and updated, solving many mistakes and mysteries like M47.

Using your imagination

Sometimes the stars themselves don't disappear but what they represent does. Every culture has used imagination to populate the sky with constellations. There are now 88 official constellations, but that hasn't always been the case. The ancient Greeks visualized 48 constellations. All but one — Argo Navis — still endure on modern star charts. Over the centuries, European astronomers added more constellations, some of which remain while others have been lost.

The 17th and 18th centuries saw many constellations added to the original 48. French astronomer Nicolas-Louis de Lacaille came up with 14. Edmond Halley, of comet fame, created Robur Carolinum (Charles' Oak) in honor of England's Charles II. (During the English Civil War, Charles hid in a great oak tree to escape capture.) Halley wanted to impress the king who had paid for his expedition to the Southern Hemisphere by giving Charles a place in the heavens. The Oak was near Argo Navis in the southern sky. Both are now lost and mostly forgotten, their stars reassigned to other constellations by later astronomers.

Searching for light

Constellations may vanish from star maps, but the stars remain. Or do they? At the Institute for Theoretical Physics in Stockholm, Sweden, a team of researchers led by Beatriz Villarroel is searching for stars that may have vanished. Project VASCO (Vanishing and Appearing Sources during a Century of Observations) is designed to search for these missing stars.

Most disappearing stars, like Tycho's star of 1572, have been found. The expanding shell of Tycho's star was pinpointed by radio astronomers at Jodrell Bank Observatory in England in 1952. Even the supernova of 1054, which created the Crab Nebula (M1), has been pinned down. These disappearing stars and others like them have left traces. But can a star vanish without leaving any evidence that it ever existed?

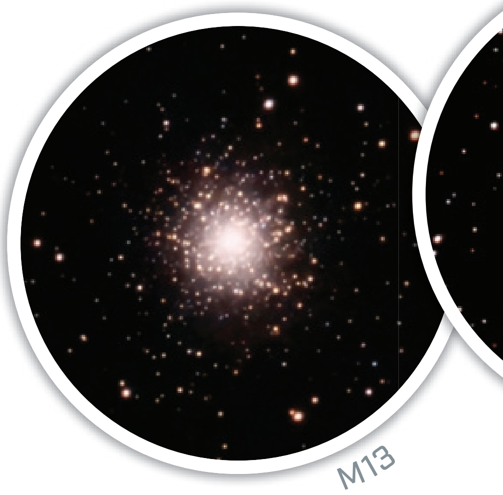
Villarroel and her team have found around 800 candidates for vanishing stars. Many of these may be supernovae, but there are some other intriguing suggestions to explain why some stars leave no trace when they disappear. Some supermassive stars might collapse rapidly into black holes. Another idea invokes an advanced alien civilization surrounding its home star with a Dyson sphere, capturing all of its energy but blocking the radiant light of the star.

When viewing a beautiful star-filled sky, we feel calm about the apparent unchanging nature of the universe. That feeling is shattered when "new" stars appear or vanish. But we now understand that the universe is dynamic: In the cosmos, nothing lasts forever and many mysteries wait to be solved. Bright stars may not be steadfast after all, but our curiosity is.

The bright open cluster M47 in Puppis is a naked-eye object to most observers from a dark site. Yet because of Messier's incorrect coordinates, it was "lost" to astronomers for over two centuries. BERNHARD HUBL

Contributing editor **Raymond Shubinski** *loves Sherlock Holmes, Agatha Christie, and a good cosmic mystery. He never knows where it might take him.*

Astronomy tests ZWO's Seestar S30



The author captured each of these objects with the Seestar S30. He then processed each image with GIMP. PHIL HARRINGTON (4)

With sharp optics, precise tracking, and a built-in filter set, this scope offers a great way to get into imaging.

BY PHIL HARRINGTON

The smart telescope revolution continues to grow, with ZWO as one of the leading innovators. Last year, the company introduced the least expensive "smarty" yet: the Seestar S30.

The S30 is a compact, all-in-one astroimaging system. Like its larger sibling, the Seestar S50, the S30 includes pretty much everything you need to capture impressive images of your favorite deep-sky objects. It comes with a small tabletop tripod, a USB-C charging cable, and a solar filter, all neatly stored in a custom-fitted soft case.

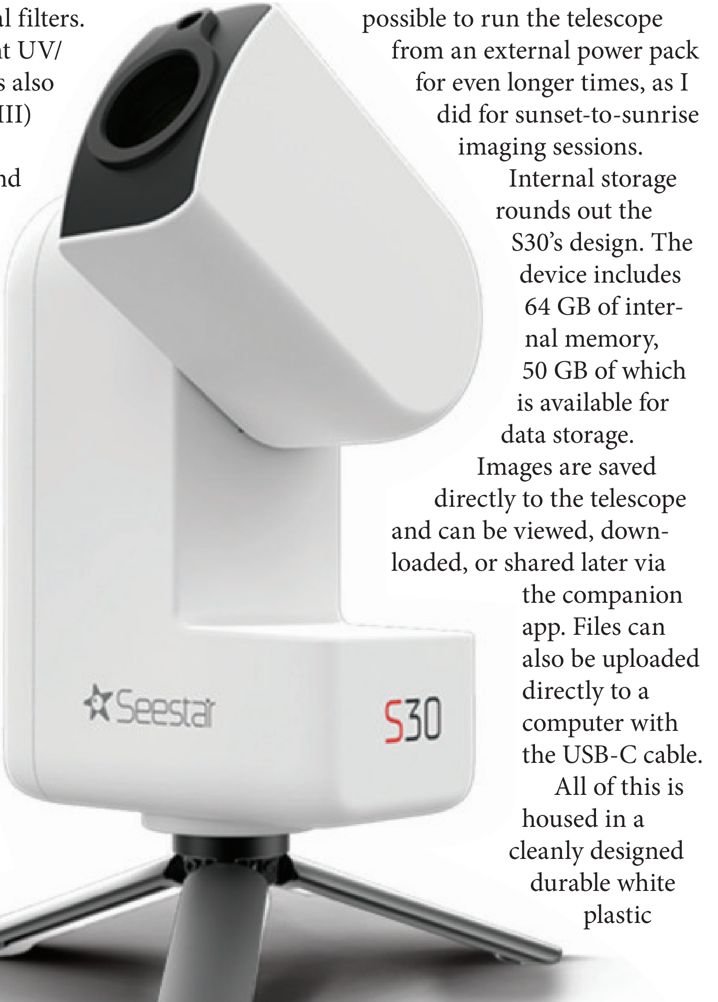
What's inside

At the heart of the Seestar S30 lies a 30mm f/5 apochromatic triplet lens, incorporating extra-low dispersion (ED) glass to minimize chromatic aberration and deliver sharp, high-contrast images. Its focal length of 150 millimeters is well-matched to the sensor and produces a field of view ideal for capturing large swaths of the sky (1.22° x 2.17° in normal mode).

The S30 is more than just optics — it's a fully integrated imaging platform. Internal motors control the mount and lens assembly, providing quiet, precise tracking slewing to targets. These motors are fast and responsive, which helps the telescope quickly acquire new targets and keep them centered during long imaging sessions. There's no need for users to worry about polar alignment or locating objects; once set up, the Seestar does the heavy lifting.

Adding to the ease of use are the Seestar's internal filters. Besides a permanent UV/IR-cut filter, there is also a dual-band (Hα/OIII) filter for imaging emission nebulae and a filter for taking dark frames to reduce noise in long exposures. These filters automatically deploy depending on the target selected in the app, though users have the option to select or deselect the dual-band filter.

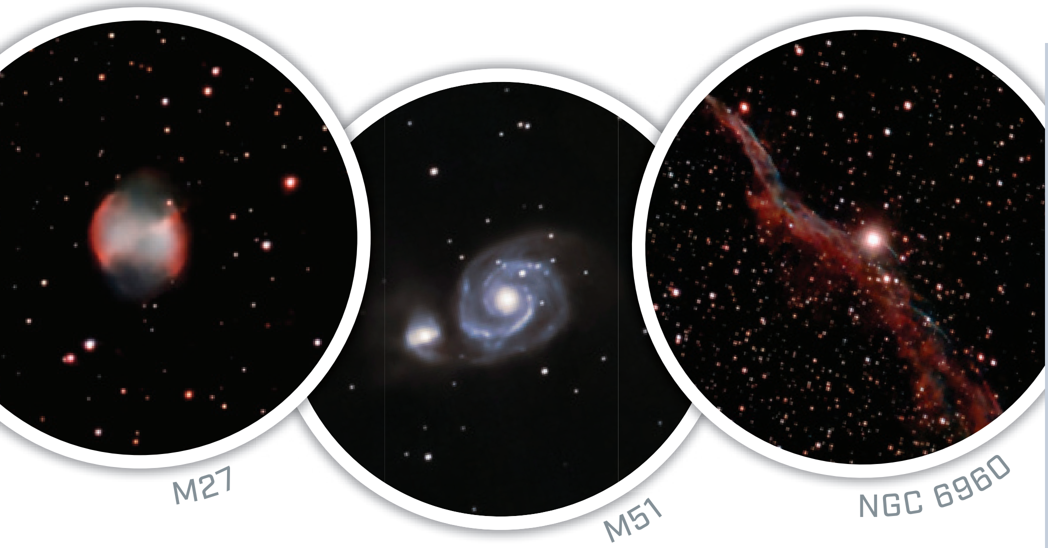
Powering all this technology is a built-in rechargeable lithium battery. On a full charge, the Seestar S30 can operate for up to six hours (less in cold weather). This is more than enough for a typical evening, especially since the telescope goes into a low-power idle state when not actively imaging. The battery charges via an included USB-C cable. It's also possible to run the telescope from an external power pack for even longer times, as I did for sunset-to-sunrise imaging sessions.



ZWO's Seestar S30 is a highly portable, self-contained imaging system at an attractive price. ZWO

Internal storage rounds out the S30's design. The device includes 64 GB of internal memory, 50 GB of which is available for data storage. Images are saved directly to the telescope and can be viewed, downloaded, or shared later via the companion app. Files can also be uploaded directly to a computer with the USB-C cable.

All of this is housed in a cleanly designed durable white plastic



PRODUCT INFORMATION

ZWO Astro Seestar S30
Aperture: 30 millimeters
Lens: Apochromatic triplet
Focal ratio: f/5
Focal length: 150 millimeters
Sensor: IMX662
Resolution: 1920x1080
Mount: Alt-azimuth
Slew rate: 1x to 1440x
Dimensions: 8.3 by 5.5 by 3.2 inches (21 by 14 by 8 cm)
Weight: 3.64 pounds (1.65 kg)
Price: $399
Contact: ZWO
Moon Bay Road 6#
Suzhou Industrial Park
Jiangsu Province, China
+86-512-6592-3102

body. The S30 weighs only 3.6 pounds (1.7 kg) and measures just 8.3 by 5.5 by 3.2 inches (21 by 14 by 8 cm). That's light enough to fit in a backpack, making it perfect for star parties and camping trips. It's also an ideal travel companion.

Setup and use

One of the Seestar S30's greatest strengths is how easy it is to get up and running. Everything arrives securely in the custom carrying case.

On my first night, I set up the S30 before sunset to connect it to my phone (a tablet works, too). Initial setup involves pressing and holding the telescope's power button until it beeps twice and announces, "Ready to Connect." It then connects to the Seestar app via the S30's internal Wi-Fi network. This "Access Point Mode" is ideal for first-time use.

For future sessions, however, "Station Mode" allows the S30 to connect to your home Wi-Fi network. This mode enables more stable and extended-range operation and helps with updates.

The Seestar app's intuitive interface is divided into a star atlas, object catalog, image gallery, and imaging controls. The star atlas is a map that overlays the positions of objects based on your location and time. Tapping on any one brings up a detailed description, an image preview, and a "GoTo" button that centers the target. The app also offers an optional "EQ mode" to reduce field rotation during long exposures.

After the scope self-aligns to the sky, aiming the S30 and taking images is as simple as selecting a target, framing the shot, and pressing "Capture." The Seestar then begins an automated imaging sequence. It takes multiple short exposures and stacks them in real time.

ZWO includes a scheduling feature that let me plan a night's imaging session in advance by queueing up a list of objects, and setting start and end times. After dark, all I had to do was choose "Execute" and the Seestar operated autonomously throughout the night.

Image quality can be enhanced using the app's AI Denoising function. This feature reduces background noise while preserving detail. The Seestar's AI algorithm is remarkably refined. Nebulae maintain their structure, stars remain sharp, and the background becomes smoother and more natural looking. Image quality may be further enhanced using third-party apps.

Imaging

When I aimed the S30 skyward, my first target was the Hercules Cluster (M13). As each 10-second subframe was added to the image, I watched on my phone's screen as the cluster resolved beautifully into pinpoints. I was amazed that the S30 also recorded the 12th-magnitude galaxy NGC 6207 that lies ½° northeast of M13, as well as the 13th-magnitude galaxy IC 4617, which sits ¼° to the cluster's northeast. Not bad for a 20-minute total exposure using a 30mm aperture under light-polluted suburban skies.

I was impressed with images of several showpieces, including Bode's Galaxy (M81) and the Cigar Galaxy (M82), the Whirlpool Galaxy (M51), the Needle Galaxy (NGC 4565), and the Southern Pinwheel Galaxy (M83). Each revealed detail that belied the 30mm aperture.

The S30 also captured stunning images of nebulae. Despite the presence of a nearly Full Moon low in the sky, both the Witch's Broom (NGC 6960) and the Eastern Veil Nebula (NGC 6992) turned out beautifully. After using the AI-based denoising to reduce image noise, I imported each image into GIMP (a free and open-source image editor) to enhance them. This revealed details that weren't visible in the original images.

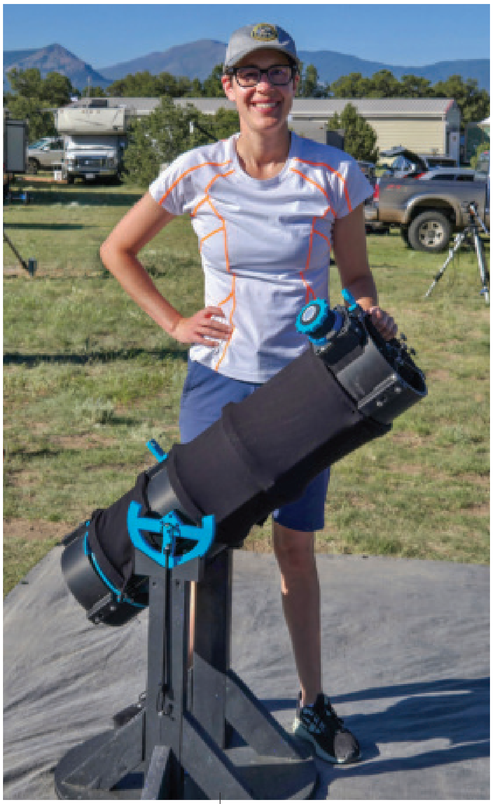
Conclusion

ZWO has another big winner with the Seestar S30. The S30 is an outstanding combination of optics, automation, and user-friendly software all at an amazingly low price. Its compact design, advanced features, and intelligent app make it one of the most approachable smart telescopes on the market today. Whether you're just wading into the shallow end of the astroimaging pool or looking for a compact, travel-friendly companion to a larger rig, the Seestar S30 promises an enjoyable experience under the stars. I only wish I had one when I first started out on my own astronomical journey.

Phil Harrington *is a contributing editor of* Astronomy *and an equipment guru who always wishes products came out 20 years before they appeared.*

Can you 3D-print a telescope?

This project will generate lots of chatter at events.



The author and her 3D-printed telescope at the Rocky Mountain Star Stare. MOLLY WAKELING

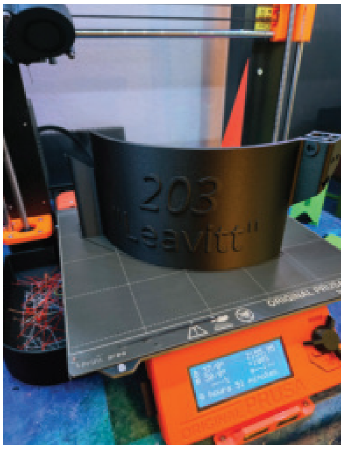
BY MOLLY WAKELING
Molly is an avid astrophotographer active in STEM outreach. She has a Ph.D. in nuclear engineering.

Since 3D printing became accessible to the average consumer in the 2010s, the internet has exploded with printable designs from creators around the world. Sites like Thingiverse and Printables host millions of downloadable files, and decent printers can be had for as little as $200. I got a Prusa i3 Mk3s+ for Christmas in 2022 and have scarcely stopped printing since. One of my most ambitious projects so far? A fully functional 8-inch f/5 Newtonian telescope.

This 3D-printed Dobsonian, called the Leavitt after astronomer Henrietta Swan Leavitt, was designed by a Printables user named Novel Tinker. Not every component is printed, of course — I had to buy metal fasteners, springs, glue, truss rods, and the mirrors. But Novel Tinker provided a detailed parts list and assembly instructions, even recommending a specific set of mirrors from eBay. (Any 8-inch mirror will work, though, and you can adjust the truss length to accommodate faster focal ratios if desired.)

For printing, I used a carbon fiber High-Temperature Polylactic Acid (HTPLA) composite from Protopasta instead of regular PLA. While more expensive at $80 per kilogram, it is more rigid and less reflective than regular PLA. Most importantly, it is heat treatable. Regular PLA softens around 120 degrees Fahrenheit (48.9 degrees Celsius), which isn't ideal for gear left in a hot car at summer star parties. Heat-treated PLA will stay rigid until 310 F (154.4 C).

The base is made from wood because it's too large for most printers. I used OSB circles and 2x4s, painted black with a sparkle additive and splattered with glow-in-the-dark paint for a starry effect. Instead of metal truss tubes, I opted for lightweight pultruded carbon fiber rods. The scope itself weighs just 8 pounds (3.6 kg), and the base 16 pounds (7.3 kg). Bungee cords create adjustable friction for the altitude axis, and Teflon furniture feet ensure smooth azimuth movement.



One of the components of the Leavitt comes to life on the author's 3D printer. MOLLY WAKELING

The focuser is unique: A threaded tube moves in and out by rotating a ring and is locked by two thumbscrews. The eyepiece is secured via a collet and nut. My only complaint is that the thread pitch is too fine — it takes many turns to change focus between eyepieces.

So, how does it perform? I tested it out at the Rocky Mountain Star Stare in Colorado this June and was impressed! Stars were sharp to the edges, collimation was easy and stable, and views were what you'd expect from a solid 8-inch. It even won an award in the star party's amateur telescope-making competition.

> **Stars were sharp to the edges, collimation was easy and stable, and views were what you'd expect from a solid 8-inch.**

Cost-wise, it ended up being more expensive than I'd hoped — you could get a larger manufactured Dob for about the same price. A few printing mistakes and broken parts meant I needed extra filament, and ordering fasteners from Amazon forced me to buy more than I needed. Local hardware stores might have saved me some money there.

So, why spend all the time, money, and effort making a 3D-printed telescope when I already own a nice 12-inch Dob? Simple: It was fun! The challenge was rewarding, and the novelty will be a hit at star parties and outreach events. Plus, it's modular — any part can be redesigned and reprinted as needed. If you have a 3D printer and want a fun, satisfying project, I highly recommend giving this telescope a try. Good luck!

BROWSE THE "OBSERVING BASICS" ARCHIVE AT
www.Astronomy.com/author/molly-wakeling

Observe from a table

Celestron

Torrance, California

Celestron's Moon Mission 100mm Tabletop Dobsonian is a 4-inch f/4 reflector. It comes with two eyepieces, a finder scope, and a Moon filter. The assembled unit weighs 5.3 pounds (2.4 kilograms), and the optical tube measures 14.2 inches (361 millimeters) long.

$109.95

1-310-803-5955

www.celestron.com

Attention, manufacturers: To submit a product for this page, email **products@astronomy.com***.*

Complete system

Explore Scientific

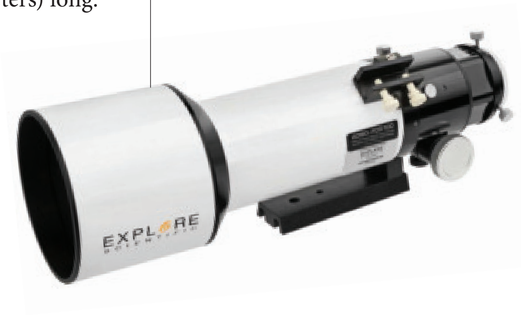
Springdale, Arkansas

Explore Scientific's ED80-FCD100 Refractor is available in a kit that comes with a 0.8x focal reducer, changing the focal ratio of this 4-inch scope from f/6 to f/4.8. The company also includes its go-to mount, a 2.5-inch focuser, a 2-inch diagonal, and two counterweights.

$1,399.98

1-866-252-3811

www.explorescientific.com



Sharp view

Tele Vue Optics

Chester, New York

The 19mm Nagler Type 7 eyepiece offers a mix of sharpness and correction. It contains seven lens elements, has an 82° apparent field of view, and weighs 19.6 ounces (556 grams). It has 19mm of eye relief and comes in a 2" model.

$635.00

1-845-469-4551

https://televue.com

FROM THE LEFT: CELESTRON; EXPLORE SCIENTIFIC; TELE VUE

MARKETPLACE

INDEX *of* ADVERTISERS

AP Grzegorz Poplawski / Arch Paths 2
Astronomy's Deep Space Mysteries
  2026 Calendar 6
Bob's Knobs 47
Caravan Tours 15
Celestron 60
Chroma Technology 11
Jan F. Andrus 5
Mason Capital Partners 11
Oberwerk 11
Rainbow Symphony 47
Scope Buggy 11
Snow King Mountain Resort 5
Stellarmate 5
Subscribe to Astronomy 55
ToupTek Astronomy Cameras 11
The Space Store 57
Wes Light 5
ZWO USA 59

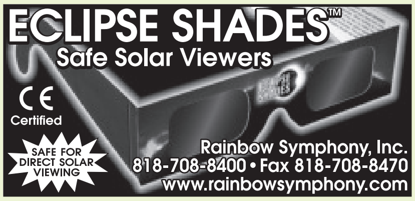
The Advertiser Index is provided as a service to *Astronomy* magazine readers. The magazine is not responsible for omissions or for typographical errors in names or page numbers.

Want more *Astronomy?*

Get your FREE weekly *Astronomy* newsletter delivered to your inbox!

Astronomy

Go to
Astronomy.com/magazine/newsletter
for more info.



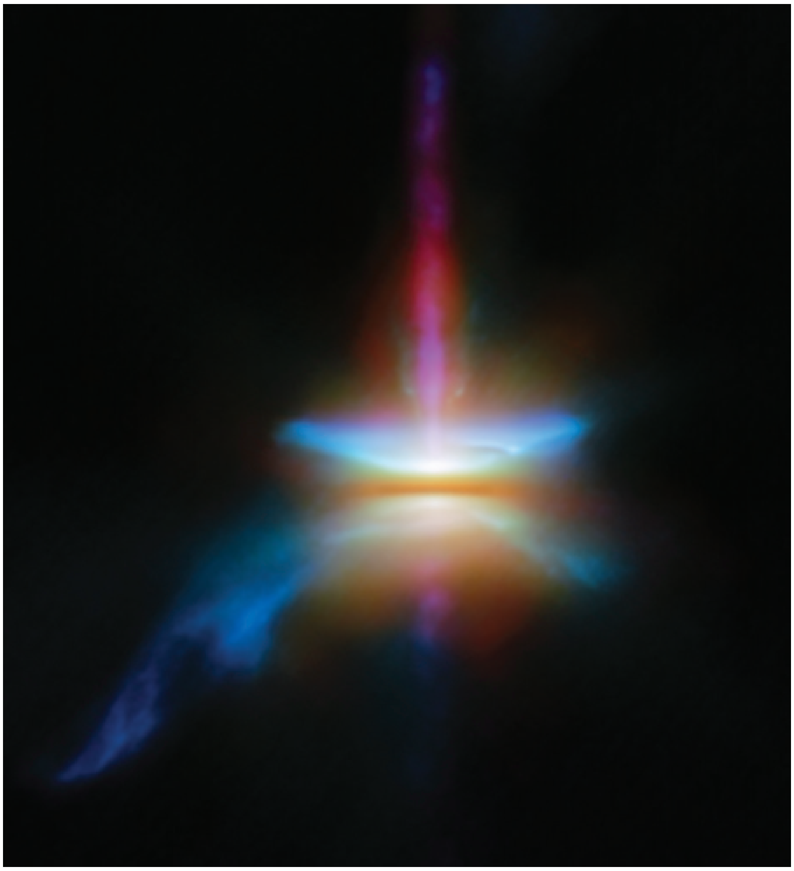
ECLIPSE SHADES™
Safe Solar Viewers
CE Certified
SAFE FOR DIRECT SOLAR VIEWING
Rainbow Symphony, Inc.
818-708-8400 • Fax 818-708-8470
www.rainbowsymphony.com

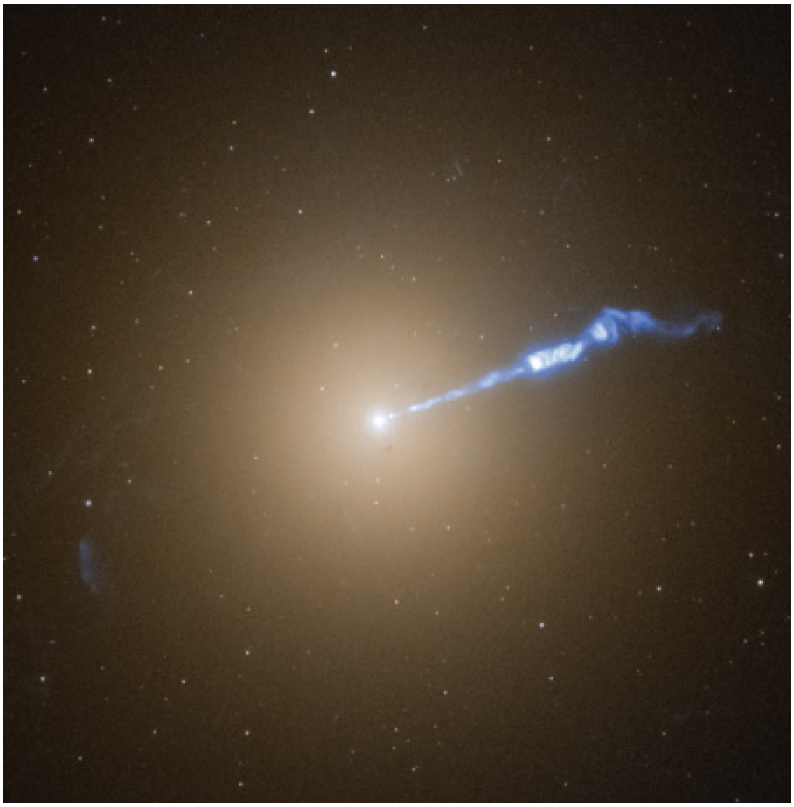
Bob's Knobs™
COLLIMATION THUMBSCREWS
www.bobsknobs.com

YOUR AD HERE

Call 608-435-6220
for advertising information

Explore the universe!
Subscribe to *Astronomy* magazine today!
Visit Astronomy.com





Cosmic jets

Q | WHY ARE THE JETS EMITTED BY BLACK HOLES OR NEUTRON STARS ALWAYS CONCENTRATED LIKE A LASER?

Craig Case
Twain Harte, California

A | Astrophysical jets are rapid outflows from a central object that become focused into a narrow cone.

Jets are everywhere in astrophysics: They occur near supermassive black holes like the 6-billion-solar-mass monster at the center of the giant elliptical galaxy M87 in Virgo (see the image at lower left) as well as near stellar-mass black holes, such as the more-than-10-solar-mass black hole in GRS 1915+105 in Aquila. Jets are found at neutron stars in supernova remnants like the famous Crab Nebula (M1), whose blast was seen in the year 1054, and also near neutron stars that draw mass from nearby companions, like Circinus X-1. Jets are also observed in gamma-ray bursts that originate from black holes and neutron stars. And they are seen near sub-solar-mass young stars such as the famous object Herbig-Haro 30 (see the image at upper left), which, as captured by the James Webb Space Telescope, looks like a beam from the Death Star.

These objects differ in size, temperature, luminosity, and nearly every other respect. But all contain jets.

The origin of jets is not yet fully understood. It is the subject of controversy, theoretical attention, and the target of countless hours of research telescope time. At least two ingredients, however, are probably needed to make jets: rotation and magnetic fields.

First, the central object (black hole, neutron star, ordinary star, etc.) must rotate, acting as a flywheel from which energy can be drawn to power the jet. That central object is invariably embedded in hot, ionized gas, in which the atoms have been stripped of some of their electrons. This makes the gas highly electrically conductive. Because the gas is conductive, it can interact with magnetic fields. The fields are caught by the central object (even if it is a black hole!) like ribbon caught on a rotating spindle.

The magnetic field connects the central object to the surrounding gas, pushing on the gas and causing it to rotate until is far from the central object. The field also draws gas inward toward the axis of rotation, focusing the outflow into a jet.

This is just part of the story, because jet sources are so different. But rotation and magnetic fields, which are also everywhere in astrophysics, seem to have a part in all of them, and produce the ubiquitous laserlike jets we see.

Charles F. Gammie
Ikenberry Chair in Astronomy and in Physics,
University of Illinois Urbana-Champaign

AT LEAST TWO INGREDIENTS ARE PROBABLY NEEDED TO MAKE JETS: ROTATION AND MAGNETIC FIELDS.

Q | WHAT IS THE ORIGIN OF THE LETTERS USED IN STAR CLASSIFICATION? WHY DIDN'T ASTRONOMERS USE ABCD?

J. Haldiman
Chicago, Illinois

A | Stellar spectral types originally followed alphabetical order. But as astronomers observed more stars and obtained more detailed spectra, they consolidated some categories and reordered the remaining ones. This left seven basic stellar types, designated OBAFGKM, which generations of astronomers and science-fiction readers have learned through the mnemonic "Oh, Be A Fine Girl (or Guy), Kiss Me."

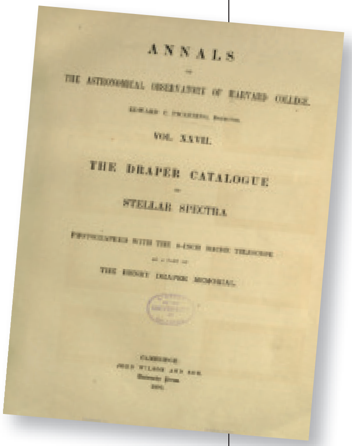
In 1866, Angelo Secchi, a Jesuit astronomer working at the Vatican Observatory, surveyed some 4,000 stars and classified them by the visual appearance of their spectra. He divided stars into four broad, numbered categories based on common spectral features.

Henry Draper, an American physician, amateur astronomer, and pioneer in photography, recorded the first image of a stellar spectrum (Vega) in August 1872. After Draper's death in 1882, his wife Anna established a memorial fund to support the development of photographic techniques in astronomy. This fund paid for the largest effort to classify stellar spectra attempted at the time — and the one that established the peculiar spectral alphabet we have today.

Between 1886 and 1897, Edward C. Pickering of Harvard College Observatory led a survey in which stellar spectra were photographed and classified by the thousands. Initially, Pickering assigned each spectral type a letter of the alphabet based on the strength of the star's hydrogen, with A being the strongest. The result of this monumental effort, the *Henry Draper Catalogue*, was published between 1918 and 1924 and classified 225,300 stars; later extensions brought the total to 359,083.

Under Pickering's supervision, his co-workers — particularly Williamina Fleming, Antonia Maury, and Annie Jump Cannon — gradually sorted out spectra, rearranging and combining some of the original categories. One motivation was to organize spectra so they created smooth transitions between different types. The final order actually reflects the surface temperatures of stars, with O stars being the hottest, but the Harvard astronomers didn't realize it at the time.

Francis Reddy
Senior Science Writer,
Astrophysics Science Division at
NASA's Goddard Space Flight Center,
Greenbelt, Maryland


ANNALS
THE ASTRONOMICAL OBSERVATORY OF HARVARD COLLEGE.
VOL. XXVII.
THE DRAPER CATALOGUE
STELLAR SPECTRA
THE HENRY DRAPER MEMORIAL.

OPPOSITE PAGE, TOP: Herbig-Haro 30 houses a young star at the center and is hidden by a thick disk of gas and dust, seen edge-on in this JWST image. Issuing from the star is a concentrated jet of gas, colored magenta. ESA/WEBB, NASA & CSA, TAZAKI ET AL.

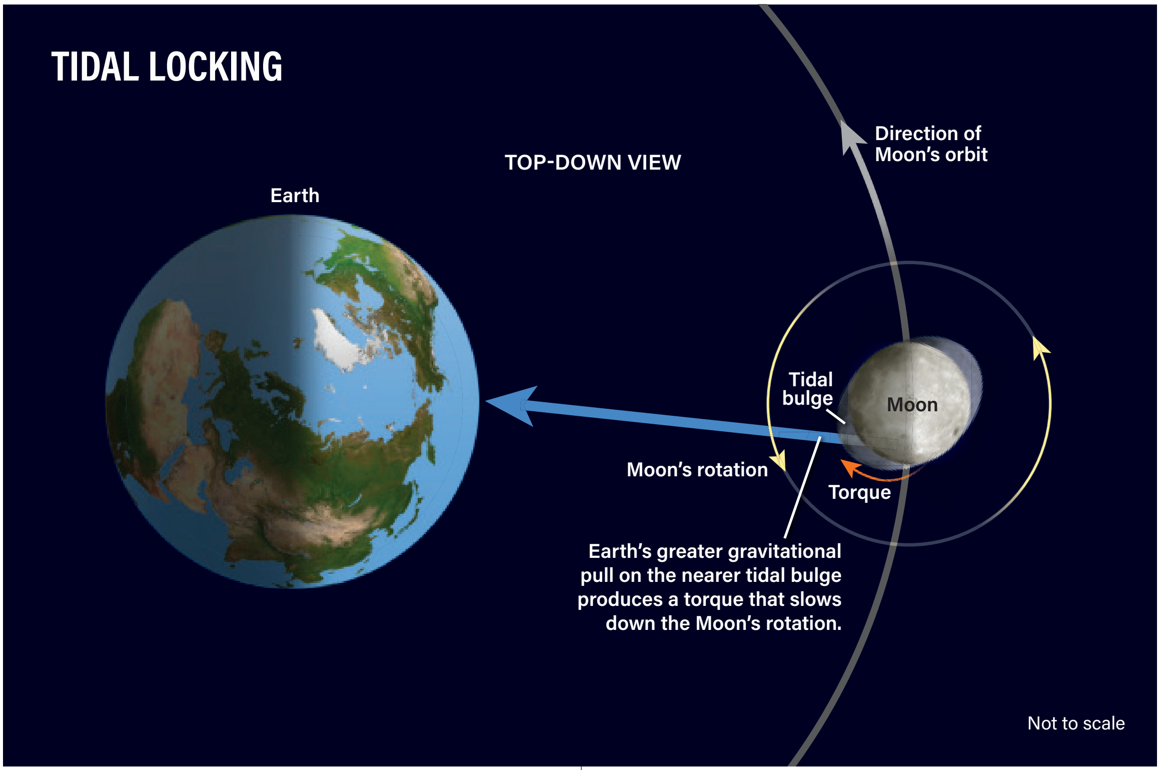
OPPOSITE PAGE, BOTTOM: This Hubble image of the giant elliptical galaxy M87 shows the 3,000-light-year-long jet generated by the galaxy's central supermassive black hole. NASA, ESA, A. LESSING (STANFORD UNIVERSITY), E. BALTZ (STANFORD UNIVERSITY), M. SHARA (AMNH), J. DEPASQUALE (STSCI)

BELOW: HARVARD COLLEGE OBSERVATORY/IMAGE FROM UNIVERSITY OF CALIFORNIA, DIGITIZED BY INTERNET ARCHIVE

STELLAR SPECTRAL CLASSES

Class	Surface temperature (kelvins)	Spectral characteristics	Example
O	28,000–50,000	Ionized helium; weak hydrogen lines	Alnilam
B	10,000–28,000	Neutral helium; stronger hydrogen lines	Spica
A	7,500–10,000	Strong hydrogen lines; plus magnesium, calcium, iron	Sirius
F	6,000–7,500	Weaker hydrogen lines; singly ionized and neutral metals	Procyon
G	4,900–6,000	Ionized calcium strongest; weaker hydrogen than F	Sun
K	3,500–4,900	Neutral metal lines predominate	Arcturus
M	2,000–3,500	Strong in neutral metals and molecules	Betelgeuse, red/brown dwarfs
L	1,300–2,000	Neutral alkali metals, hydrides	2M1507 (brown dwarf)
T	<1,300	Methane and sodium absorption	Epsilon (ε) Indi Ba (brown dwarf)

The tinted background illustrates star color for each spectral type.


TIDAL LOCKING
TOP-DOWN VIEW
Earth
Direction of Moon's orbit
Tidal bulge
Moon
Moon's rotation
Torque
Earth's greater gravitational pull on the nearer tidal bulge produces a torque that slows down the Moon's rotation.
Not to scale

Over time, Earth's gravity has reduced the Moon's rotational rate until our satellite rotates on its axis at the same rate it revolves around Earth, a situation known as tidal locking. *ASTRONOMY*: ROEN KELLY, AFTER CAROLINE HASLER

Q WHY DOES THE SAME SIDE OF THE MOON ALWAYS FACE EARTH? I KNOW THIS IS CALLED TIDAL LOCKING, BUT WHAT IS THE UNDERLYING MECHANISM FOR THIS?

Bill Carroll
Chicago, Illinois

A When the Moon first formed, it was a sea of molten lava. The immense gravity of Earth stretched this molten sea, raising tides on both the near and far sides.

But the Moon was spinning, and that rotation carried the tides away from a direct line pointing toward Earth. So, from Earth's perspective, there was an extra lump of material sitting slightly on either side of a line connecting the center of Earth with the center of the Moon. The gravity of Earth tugged on these lumps, trying to bring them back into alignment (i.e., so that the nearer bulge pointed directly at Earth, rather than slightly away). This produced torque, or an additional rotational force, that slowed down the Moon's rotation.

At first this tugging wasn't successful because the Moon had more than enough rotational energy to overcome the torque from Earth's pull and keep spinning. But over time, Earth slowly won and the Moon's rotation slowed down.

This process continued for millions of years until the lumps — the tides raised by Earth's gravity — sat permanently on a direct line facing Earth. To achieve this, the rotation of the Moon had to synchronize with its orbit, so that it always presents the same face to Earth.

It wasn't until Oct. 7, 1959, that the Soviet Luna 3 spacecraft gave humanity its first-ever look at the farside of the Moon.

Paul Sutter
Cosmologist, Johns Hopkins University, Baltimore

Q IN 2017, ASTRONOMERS FOUND HYPERVELOCITY STARS BELIEVED TO HAVE COME FROM THE LARGE MAGELLANIC CLOUD, SUPPOSEDLY KICKED OUT OF BINARY SYSTEMS BY SUPERNOVAE. WHAT KEPT THE SURVIVING STAR FROM BEING DESTROYED BY THE BLAST?

Launie Wellman
Festus, Missouri

A Some stars in our galaxy, known as hypervelocity stars, move much faster than most other stars in the Milky Way. In fact, they are traveling so fast that our galaxy's gravity can't hold onto them and eventually they will escape into intergalactic space, never to return.

Scientists believe many hypervelocity stars are flung

SEND US YOUR QUESTIONS

Send your astronomy questions via email to **askastro@astronomy.com**. Be sure to tell us your full name and where you live. Unfortunately, we cannot answer all questions submitted.

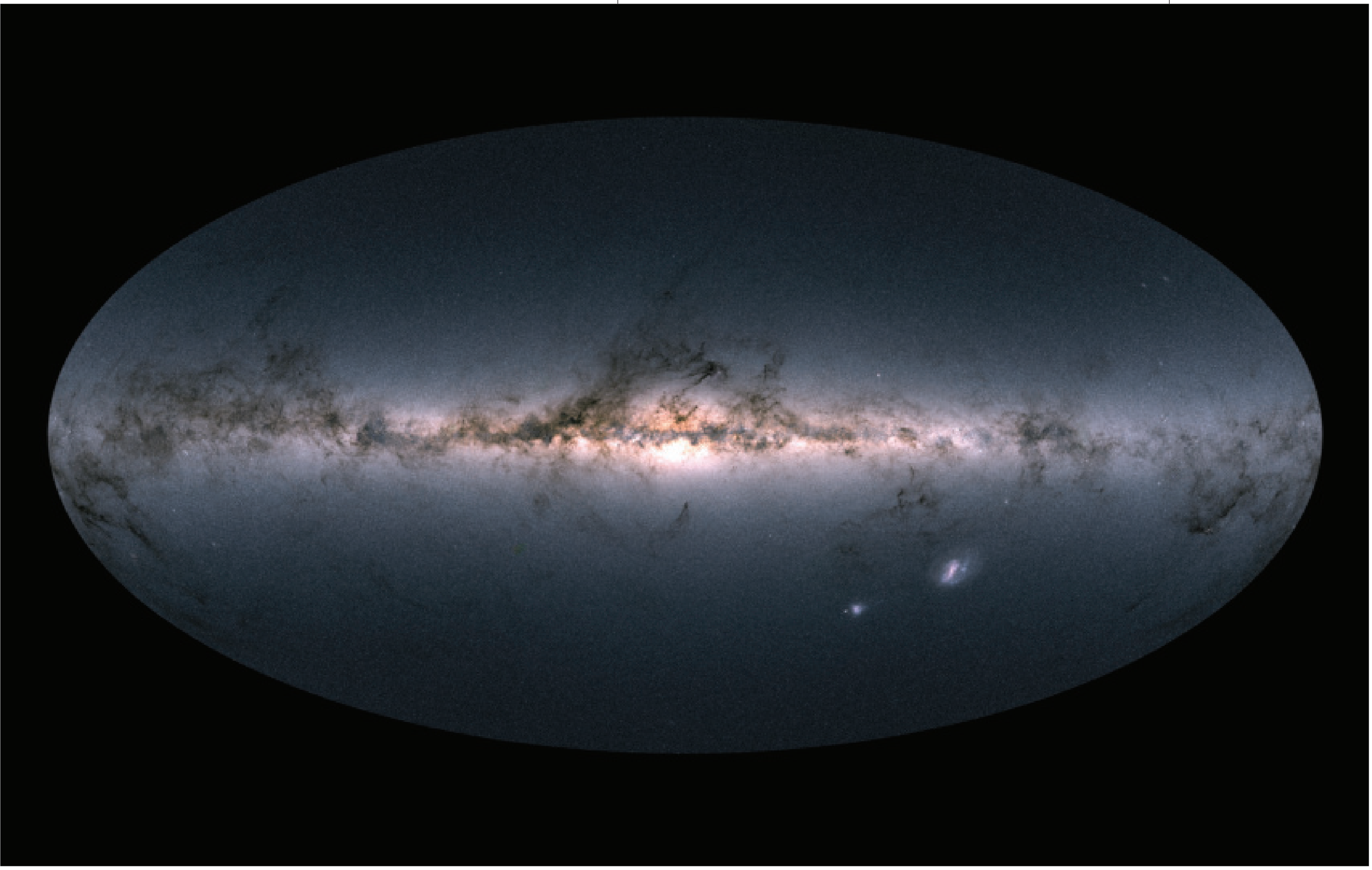
out when two stars orbiting each other (a binary star system) get too close to the enormous black hole at the center of the Milky Way, called Sagittarius A*. The black hole's powerful gravity can tear the pair apart, capturing one star while slingshotting the other away at thousands of miles per second — far faster than our Sun's orbital speed of nearly 140 miles (220 kilometers) per second.

If all hypervelocity stars came from the center of the Milky Way in this way, we'd expect to see them scattered evenly across the sky. However, a surprising number have been found in one particular area: the constellations Leo and Sextans. A 2017 study suggested that those hypervelocity stars may have been ejected from a different source: the Large Magellanic Cloud (LMC), a small neighboring galaxy orbiting the Milky Way.

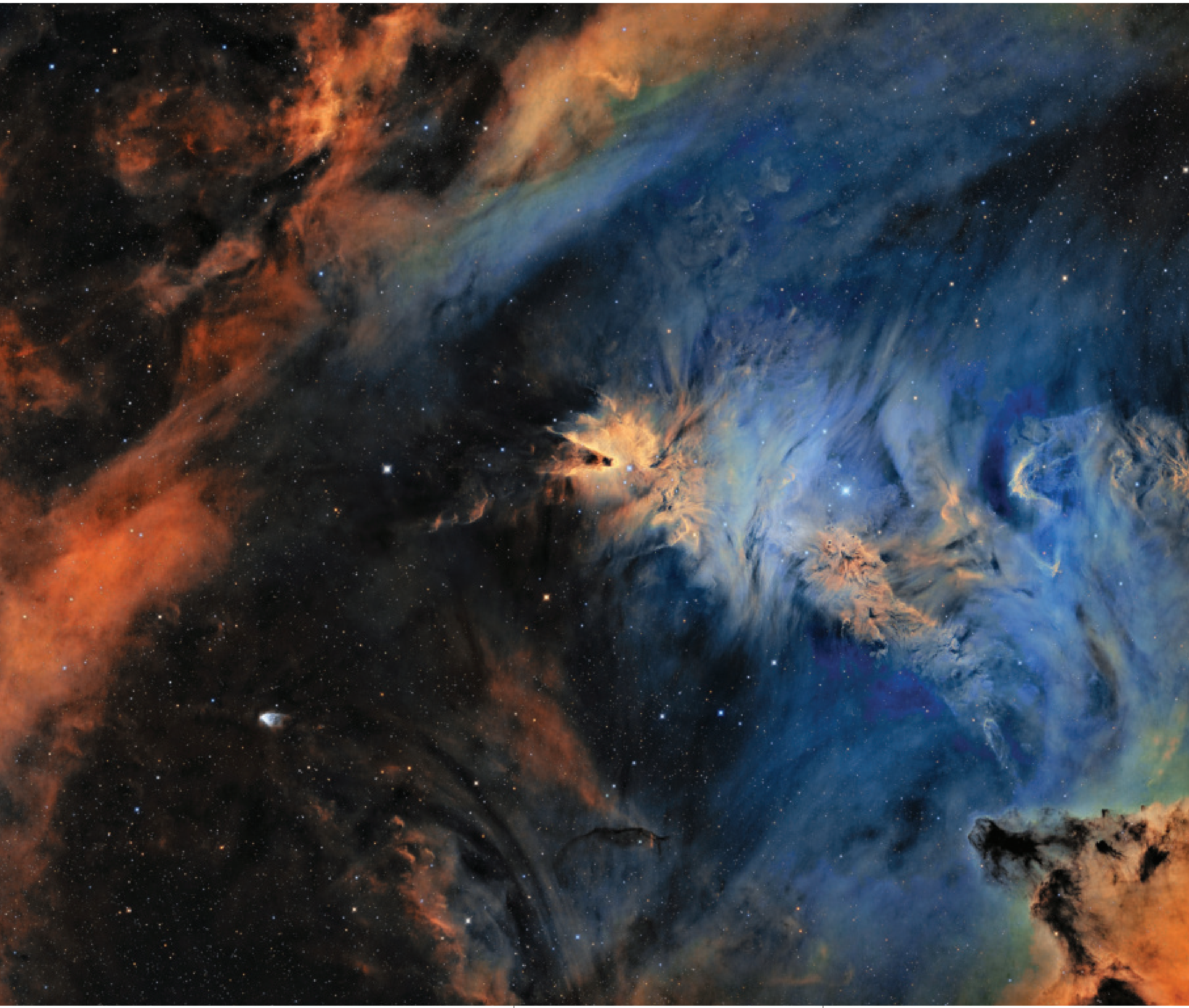
This could happen if one star in a binary system explodes as a supernova. Normally, binary stars orbit each other at high speeds to avoid crashing. But when one star explodes, the other can fly away at its orbital speed. Since the LMC itself is moving at 250 miles (400 km) per second, depending on the ejected star's direction, its speed (as seen by us) could add up to match that of hypervelocity stars caused by interactions with Sagittarius A*. And we'd see them all in the area of Leo and Sextans because the stars are ejected along the orbit of the LMC, which flings them in the direction of these particular constellations.

Interestingly, when a supernova explodes, it doesn't destroy its companion star — or any planets that might be orbiting it. While a nearby supernova would be dangerous to life on Earth by damaging our atmosphere with high-energy radiation, it wouldn't physically destroy the planet. Similarly, a companion star might lose some of its outer layers due to a nearby supernova, but the star's self-gravity keeps the bulk of it intact. In fact, many binary stars stay together even after a supernova, forming what are known as X-ray binaries, where a normal star orbits a dense neutron star or black hole that formed from the core of the star that exploded as a supernova. In such X-ray binaries, the strong gravitational tides from the neutron star or black hole rip off the outer layers of the normal companion, creating an accretion disk that glows in X-rays. The Milky Way is teeming with such X-ray binaries.

Monica Valluri
Research Professor of Astronomy, University of Michigan, Ann Arbor, Michigan



This all-sky map produced by the Gaia mission shows the plane of our Milky Way running through the center, as well as the Large and Small Magellanic clouds at lower right. The LMC may be the source of a particular group of fast-moving stars, which largely appear along its projected orbit on the sky. ESA/GAIA/DPAC



1. STELLAR NATIVITY SCENE

The Christmas Tree Cluster lies at the center of this image, filled with young, newborn stars and surrounding nebulosity cataloged as NGC 2264. That includes the Cone Nebula, just left of center. The Fox Fur Nebula lies directly below the bright blue star (S Monoceros) at center. This image comprises 25¼ hours of exposure in SHO filters with an 8-inch scope. ▪ ***Simon Todd***

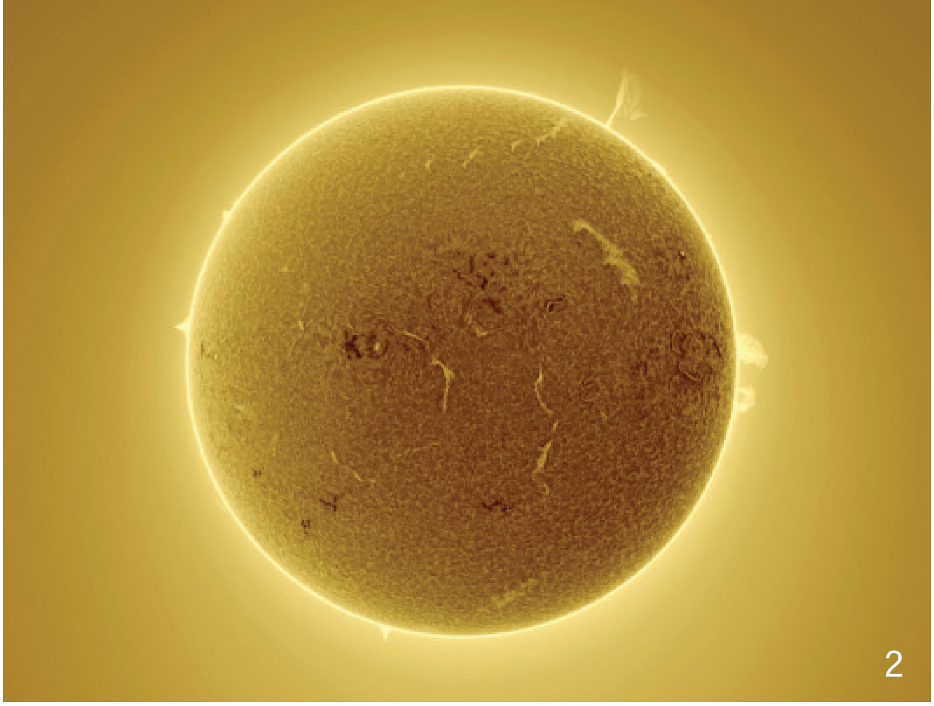
2. OUR STAR IN ACTION

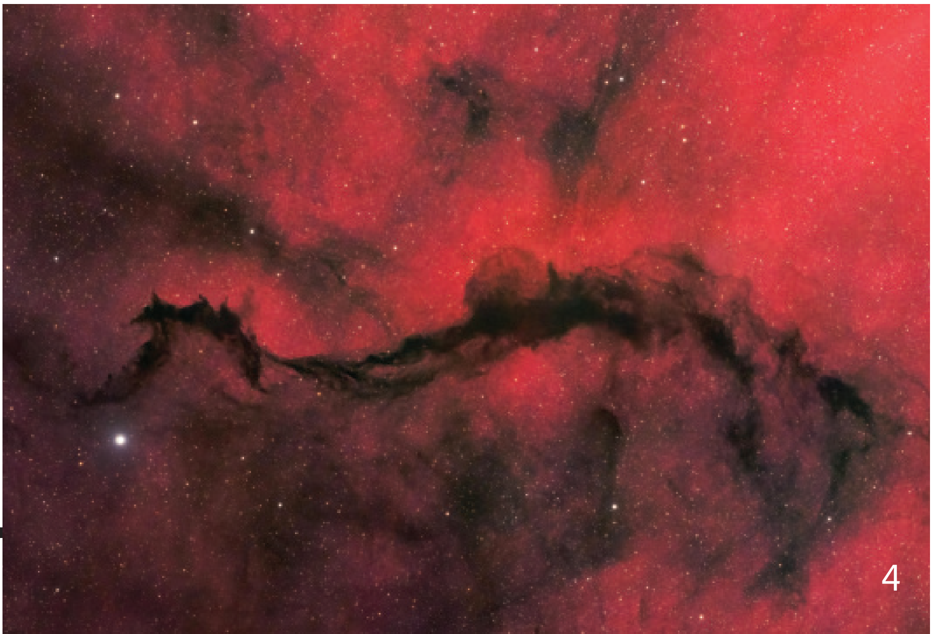
Solar prominences and intricate surface texture dot this view of the Sun, highlighting the dynamic activity of our nearest star in Hα light. The image was captured June 28 with a Lunt 50mm solar telescope and monochrome camera. ▪ ***Rich Ruffini***

3. SHELLS OF ITS FORMER SELF

The elliptical galaxy NGC 474 (lower right) contains multiple shell-like structures and tidal tails as a result of past interactions with other galaxies. The galaxy is currently interacting with a neighboring spiral galaxy just to its left, NGC 470. The lenticular galaxy NGC 467 (at left) is a background galaxy, more than twice as distant. The imagers used a 24-inch scope to capture 20 hours of data. ▪ ***Adriano Anfuso/Vikas Chander***

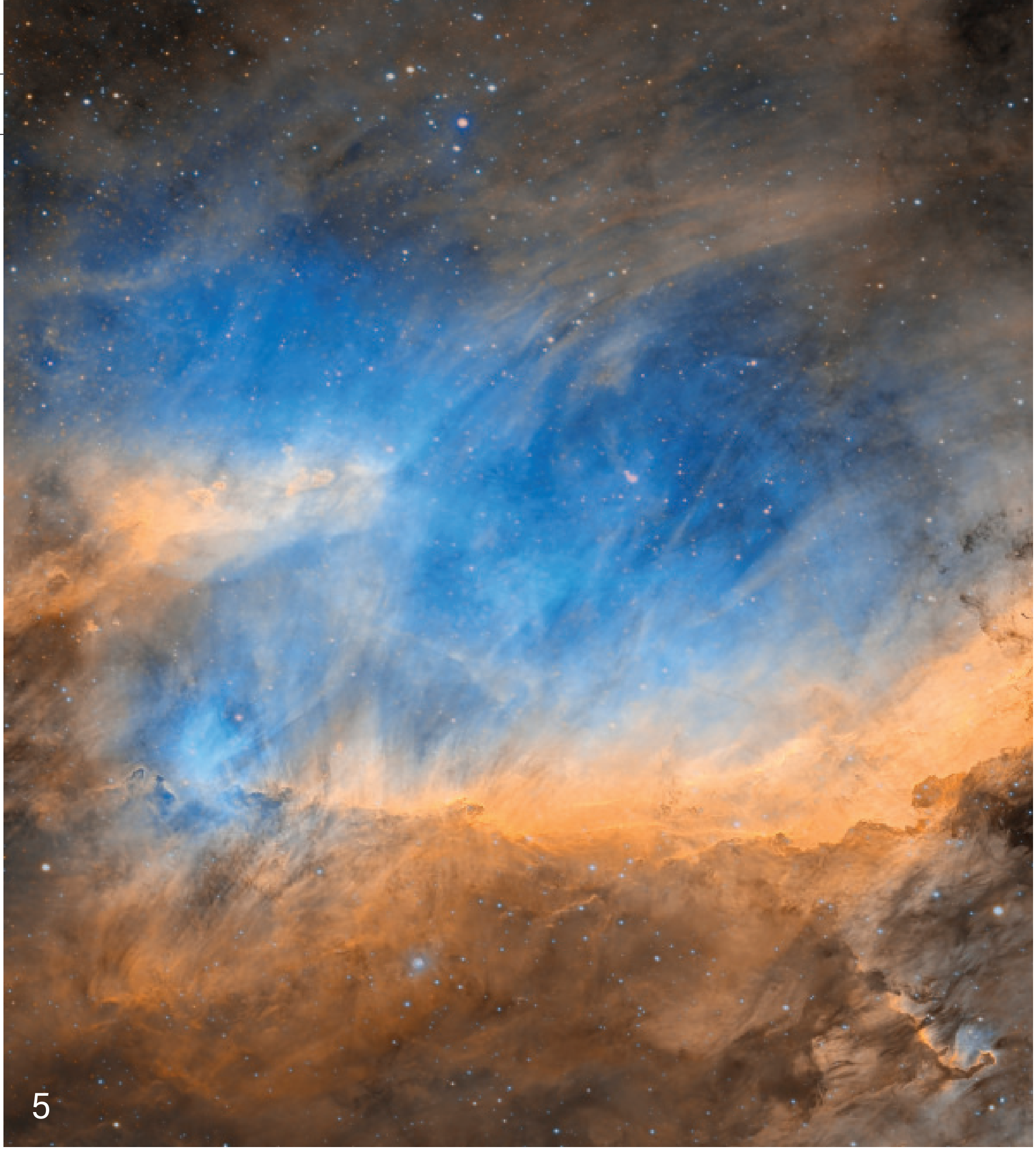
4. THE DARK VEIL
This wispy object in Ophiuchus is cataloged as LDN 204, 234, and 191. The imager suggests the moniker of "the Dark Veil" due to its resemblance in shape to NGC 6960, also known as the Western Veil Nebula or the Witch's Broom. The image comprises 37.1 hours of exposure taken with a 2.8-inch f/5.6 scope in HαLRGB filters. ▪ ***Katelyn Beecroft***

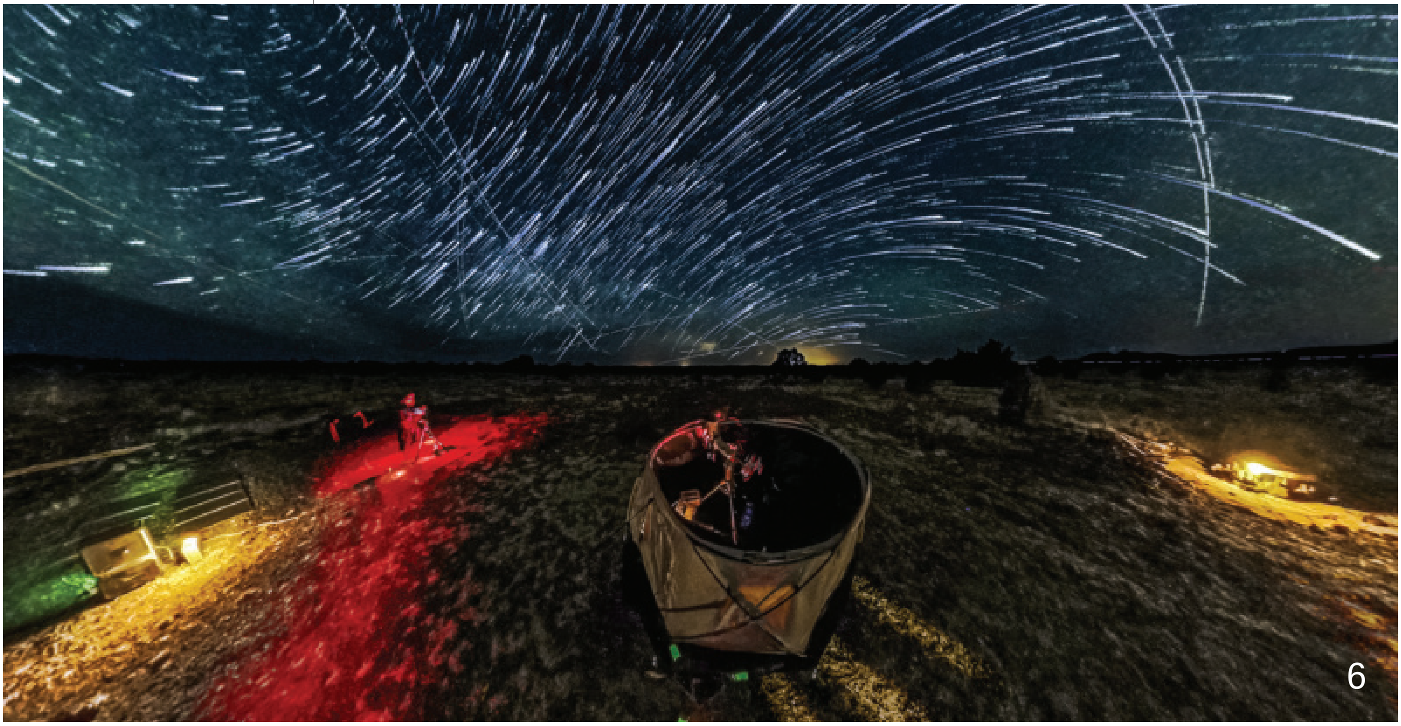




5. HOT CRUSTACEAN BANDS
The Prawn Nebula (IC 4628) lies around 6,000 light-years away in Scorpius and displays striking striations of ionized gas sculpted by stellar winds and radiation. The photographer took 83 hours of exposure in the Hubble palette with a 6-inch f/7 refractor. ▪ ***Fernando Oliveira de Menezes***

6. A WORLD IN MOTION
Star trails encircle the landscape of northern Arizona in this 360° image that uses a stereographic projection. In the "foreground" of the scene lies the photographer's Starpoint Australis portable tent observatory. The photographer captured the star trails with an Insta360 X4 camera, stacking some five hundred 30-second images taken at f/1.9.
▪ ***Greg Meyer***





Astronomy

SAVE UP TO 54%

GET 1 YEAR OF *ASTRONOMY* FOR AS LOW AS $39.95

Astronomy
THE WORLD'S BEST-SELLING ASTRONOMY MAGAZINE /// NOVEMBER 2024
EVERYTHING WE KNOW ABOUT
THE SUN
WHAT CAUSES RAINBOWS AND MOONBOWS?
PLUS:
THE STARMUS FESTIVAL ROCKS SLOVAKIA
WEBB UNLOCKS STARBIRTH IN SERPENS
BEHIND THE SCENES AT A ROCKET LAUNCH
WHAT CAUSES RAINBOWS AND MOONBOWS?

Each year you'll receive:

- Countless observing tips ("Ask Astro!")
- Brand new Sky Guides ("The Sky This Month")
- Breaking space news and discoveries
- Understandable scientific analysis from astronomy & cosmology experts
- Breathtaking photos of the newest celestial objects
- Photo galleries showcasing our readers' best snapshots
- Unbiased reviews of all astronomical tools & equipment

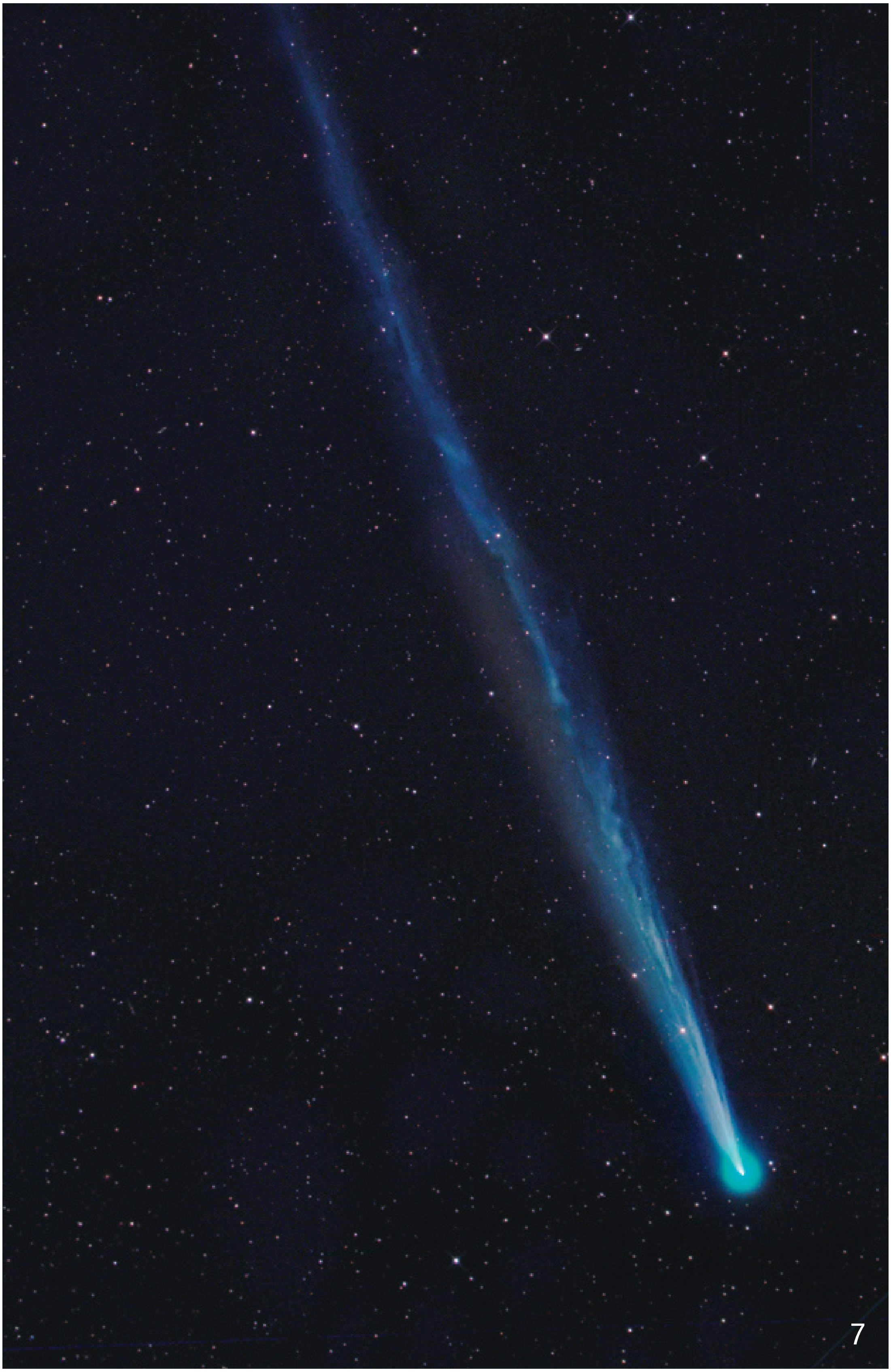
AND SO MUCH MORE!

VISIT US ONLINE:
ASTRONOMY.COM/SUBSCRIBE

SCAN ME

Studio023/Dreamstime.com

7. A MIGRATORY SWAN
Comet C/2025 R2 SWAN was discovered Sept. 11 by Ukrainian amateur astronomer Vladimir Bezugly in imagery taken by NASA's SOHO spacecraft. This astrophotographer captured the comet and its tail as it soared through the inner solar system on Sept. 16 with a 12-inch f/3.6 scope and 28 minutes of LRGB exposure.
· *Gerald Rhemann*


7

SEND YOUR IMAGES TO: readergallery@ astronomy.com. Please include the date and location of the image, your mailing address, and complete photo data: telescope, camera, filters, and exposures.

the space store®

Explore the Universe

The Space Store offers an extensive selection of space mission patches, rocket and airplane models, meteorites, toys, books, and unique items from NASA, SpaceX, Boeing, and the U.S. Space Force.

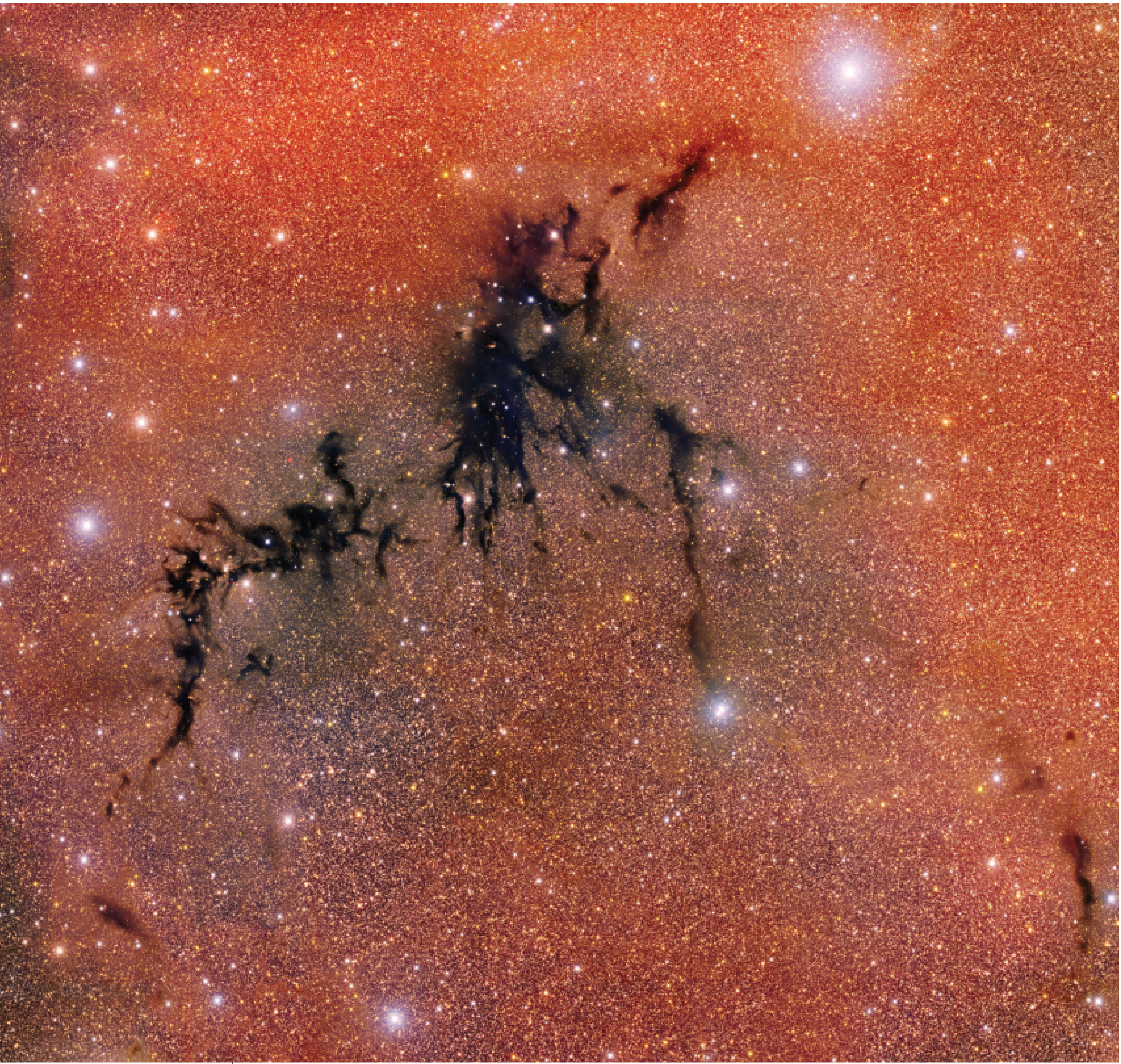
Come and check out the largest retailer of NASA and space-themed collectibles, apparel, and gifts, serving enthusiasts of all ages!

Shop now at: TheSpaceStore.com/Shop

connecting you to the cosmos

UNITED STATES
SPACE FORCE

MCCLAIN
HYERS ONISHI
PESKOV



AN INKY STAIN ON A STARRY STAGE

Beauty often comes in small packages. Take Circinus the Compasses. This southern constellation ranks 85th in size among the sky's 88 stellar groupings, yet it holds the stunning dark nebula known as the Circinus West molecular cloud. A dense region of dust and cold gas, Circinus West effectively blocks all the light from the rich star background. The few bright spots poking through the cloud's dark tendrils represent baby stars just emerging from their dusty cocoons. The nebula forms the western part of the larger Circinus molecular cloud, which lies some 2,500 light-years from Earth and contains about 250,000 times the mass of the Sun. Circinus West stands just 3° southeast of brilliant Alpha Centauri. The bright star at the photo's upper right is 3rd-magnitude Theta Circini. CTIO/NOIRLAB/DOE/NSF/AURA

ZWO | Seestar

SEESTAR DIGITAL SMART TELESCOPES

DISCOVER MORE. CARRY LESS.

9:41
Enhancing
M42
02:45:56
56
AF

Seestar
S30

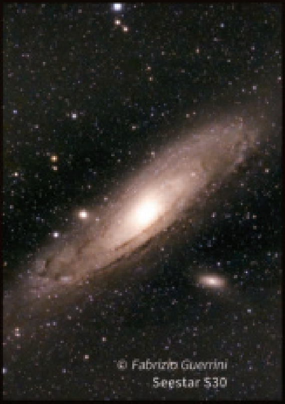
Seestar S30

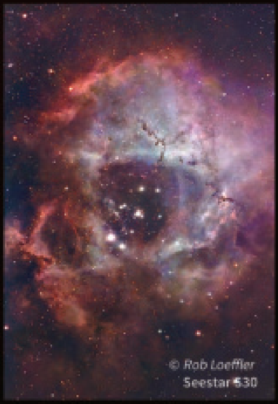
Dual-lens,
ultra-portable, and
unbeatable value

Scan to get *10%*
discount

Capture the cosmos with ease.

© Jonathan Winterbottom
Seestar S30


© Fabrizio Guerrini
Seestar S30


© Rob Loeffler
Seestar S30

store.seestar.com zwousa_info@zwoastro.com +1 (862) 352-3043

CELESTRON

Bedtime Canceled

WHEN THE NIGHT'S THIS EPIC, YOU DON'T WASTE IT ON SLEEP.

CELESTRON
NexStar 6 SE
NexStar EVOLUTION
CELESTRON
CELESTRON Origin
origin
NEW
CAMERA
SENSOR

DISCOVER GALAXIES, NEBULAE, AND STAR CLUSTERS WORTH STAYING UP FOR WITH CELESTRON.

NexStar SE

The Easy Way to Start Exploring Space

NexStar SE gives beginners an unforgettable first look at the universe. With patented SkyAlign technology, you can be observing planets and galaxies in minutes—no star charts required. Its lightweight design makes it easy to carry from the backyard to a weekend trip. And with a database of 40,000+ objects, every night out brings something new to chase.

NexStar Evolution

Powerful Optics, Wireless Freedom

For the budding astronomer ready to go deeper, NexStar Evolution blends advanced tech with premium optics. Built-in WiFi lets you control your scope via smartphone or tablet with the SkyPortal Powered by SkySafari™ mobile app. Explore with the interactive planetarium view or jump straight to Tonight's Best objects. With a 10+ hour rechargeable battery, feel free to pull an all-nighter.

Celestron Origin

Your All-in-One Intelligent Home Observatory

The future of astronomy just leveled up. Celestron Origin delivers jaw-dropping astroimages in near real-time—and now it's even better with Sony's latest Starvis 2 imaging technology. Origin autonomously aligns itself, then captures and processes your images. Its 6" f/2.2 Rowe-Ackermann Schmidt Astrograph gathers light in seconds, while the new sensor unlocks sharper detail, brighter views, and a cinematic wide field made for your screen. Sit back, relax, and watch the universe reveal itself.

Learn more and explore our Holiday Gift Guide at celestron.com/holiday

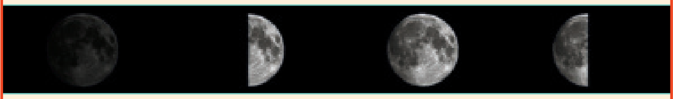
CELESTRON PREMIER SELECT DEALERS

B&H Photo – 800.947.9970 – bhphotovideo.com
High Point Scientific – 800.266.9590 – highpointscientific.com
Astronomics – 800.422.7876 – astronomics.com
Woodland Hills – 888.427.8766 – telescopes.net
Adorama – 800.223.2500 – adorama.com
Mile High Astronomy - 877.279.5280 - milehighastro.com
Focus Camera – 800.221.0828 – focuscamera.com
Agena AstroProducts – 562.215.4473 – agenaastro.com
Orange County Telescopes - 888-471-9991 – octelescope.com

SPECIAL pull-out section

Astronomy's 2026 Guide to the Night Sky

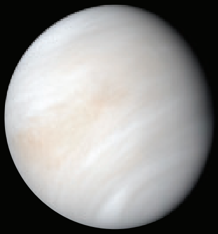
LUNAR PHASES



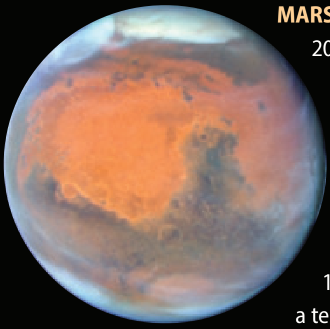
New	First Quarter	Full	Last Quarter
		Jan. 3	Jan. 10
Jan. 18	Jan. 25	Feb. 1	Feb. 9
Feb. 17	Feb. 24	March 3	March 11
March 18	March 25	April 1	April 10
April 17	April 23	May 1	May 9
May 16	May 23	May 31	June 8
June 14	June 21	June 29	July 7
July 14	July 21	July 29	Aug. 5
Aug. 12	Aug. 19	Aug. 28	Sept. 4
Sept. 10	Sept. 18	Sept. 26	Oct. 3
Oct. 10	Oct. 18	Oct. 26	Nov. 1
Nov. 9	Nov. 17	Nov. 24	Dec. 1
Dec. 8	Dec. 17	Dec. 23	Dec. 30

All dates are for the Eastern time zone. A Full Moon rises at sunset and remains visible all night; a New Moon crosses the sky with the Sun and can't be seen.

THE MOON is Earth's nearest neighbor and the only celestial object humans have visited. Because of its changing position relative to the Sun and Earth, the Moon appears to go through phases, from a slender crescent to Full Moon and back. The best times to observe our satellite through a telescope come a few days on either side of its two Quarter phases. For the best detail, look along the terminator — the line separating the sunlit and dark parts. NASA/GSFC/ARIZONA STATE UNIVERSITY



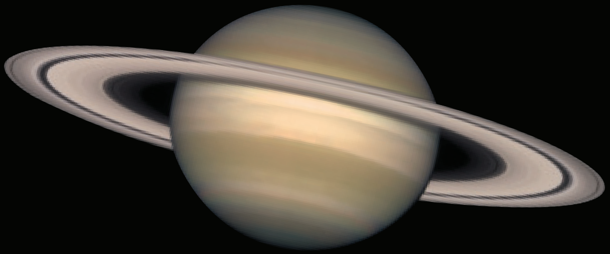
VENUS remains a fixture in the western evening sky from late February through September. It then disappears in the Sun's glare before returning to view before sunrise in early November. It peaks at magnitude –4.9 late that month, but continues to dominate the eastern predawn sky through year's end. NASA/JPL-CALTECH



MARS lies too close to the Sun to observe in early 2026 but reappears before dawn in the spring. The Red Planet grows more prominent every month as it ascends in the eastern sky. The ruddy world glows at 1st magnitude through October, but it improves rapidly as the weather turns colder. By year's end, it shines at magnitude –0.1 and shows a 10"-diameter disk when viewed through a telescope. NASA, ESA, STSCI

JUPITER always looks dramatic through a telescope. Even small instruments show the planet's four big moons and resolve its dynamic atmosphere into an alternating series of bright zones and darker belts. Jupiter appears best at opposition in early January, when it shines brightest (magnitude –2.7) and looms largest (47" across), though it's a spectacular object all year except in the weeks around solar conjunction in late July. NASA, ESA, A. SIMON (GSFC), M. WONG (UC BERKELEY), J. DEPASQUALE (STSCI)

SATURN and its rings provide a spectacular attraction for telescope owners in January and February and again from May through December. The ringed planet reaches its peak in early October. It then shines at magnitude 0.3 and its disk measures 20" across while the ring system spans 45" and tilts 7° to our line of sight. NASA/ESA/THE HUBBLE HERITAGE TEAM (STSCI/AURA)



A supplement to *Astronomy* magazine

Astronomy magazine

SUBSCRIBE TODAY!

WINTER

The sky

Winter boasts the brightest stars of any season. Orion the Hunter dominates the evening sky this time of year. Its seven most prominent stars form a distinctive hourglass pattern. The blue star marking Orion's left foot is Rigel, and the ruddy gem at his right shoulder is Betelgeuse. The three stars of the Hunter's Belt point down to Sirius, the brightest star in the night sky, and up to Aldebaran, the eye of Taurus the Bull. To Orion's upper left lies the constellation Gemini.

Deep-sky highlights

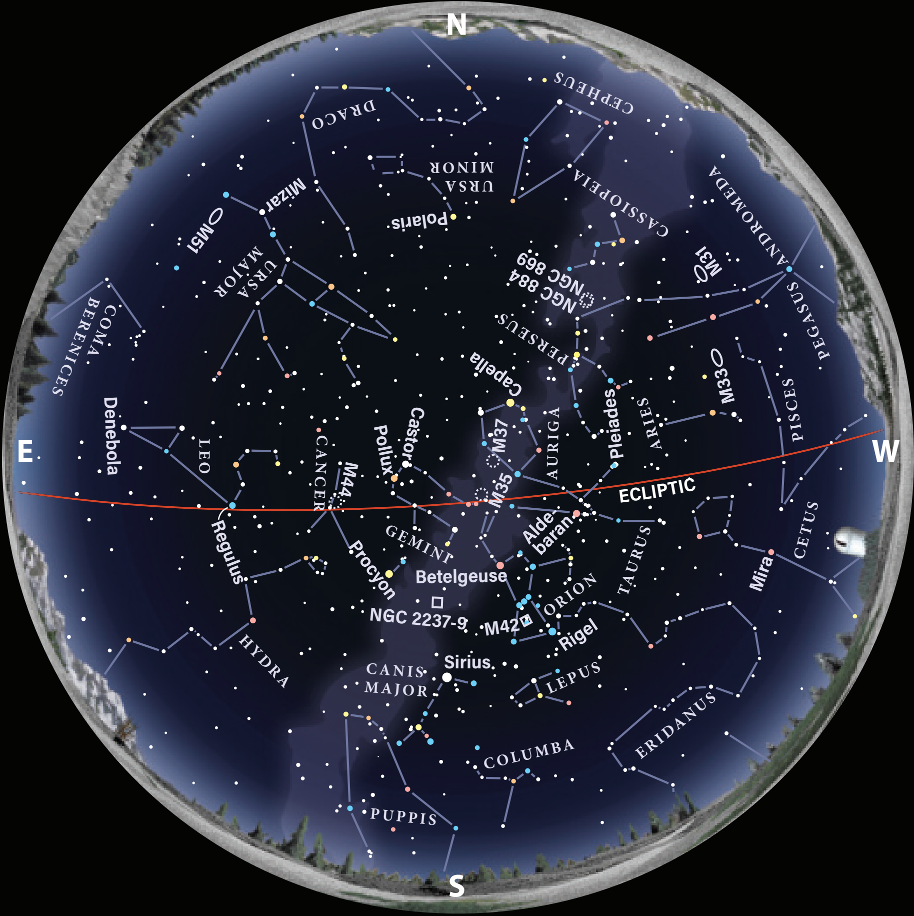
The Pleiades (M45) is the brightest star cluster in the sky. It looks like a small dipper, but it is not the Little Dipper.

The Orion Nebula (M42), a region of active star formation, is a showpiece through telescopes of all sizes.

The Rosette Nebula (NGC 2237–9/46), located 10° east of Betelgeuse, presents an impressive cluster of stars and a nebula.

M35 in Gemini the Twins is a beautiful open cluster best viewed with a telescope.

Castor (Alpha [α] Geminorum) is easy to split into two components with a small telescope, but the system actually consists of six stars.


N
E
W
S
DRACO
CEPHEUS
URSA MINOR
Polaris
CASSIOPEIA
ANDROMEDA
M31
Mizar
M51
URSA MAJOR
NGC 869
NGC 884
COMA BERENICES
PERSEUS
Capella
M33
PEGASUS
PISCES
Denebola
LEO
CANCER
Pollux
Castor
M37
AURIGA
Pleiades
ARIES
M44
M35
ECLIPTIC
CETUS
Regulus
GEMINI
Aldebaran
TAURUS
Mira
Procyon
Betelgeuse
ORION
NGC 2237-9
M42
Rigel
HYDRA
CANIS MAJOR
Sirius
LEPUS
ERIDANUS
COLUMBA
PUPPIS

SPRING

The sky

The Big Dipper, the most conspicuous part of the constellation Ursa Major the Great Bear, now rides high in the sky. Poke a hole in the bottom of the dipper's bowl, and the water would fall on the back of Leo the Lion. The two stars at the end of the bowl, called the Pointer Stars, lead you directly to Polaris, the North Star: From the bowl's top, simply go five times the distance between the Pointers. Spring is the best time of year to observe a multitude of galaxies. Many of these far-flung island universes, containing hundreds of billions of stars, congregate in northern Virgo and Coma Berenices.

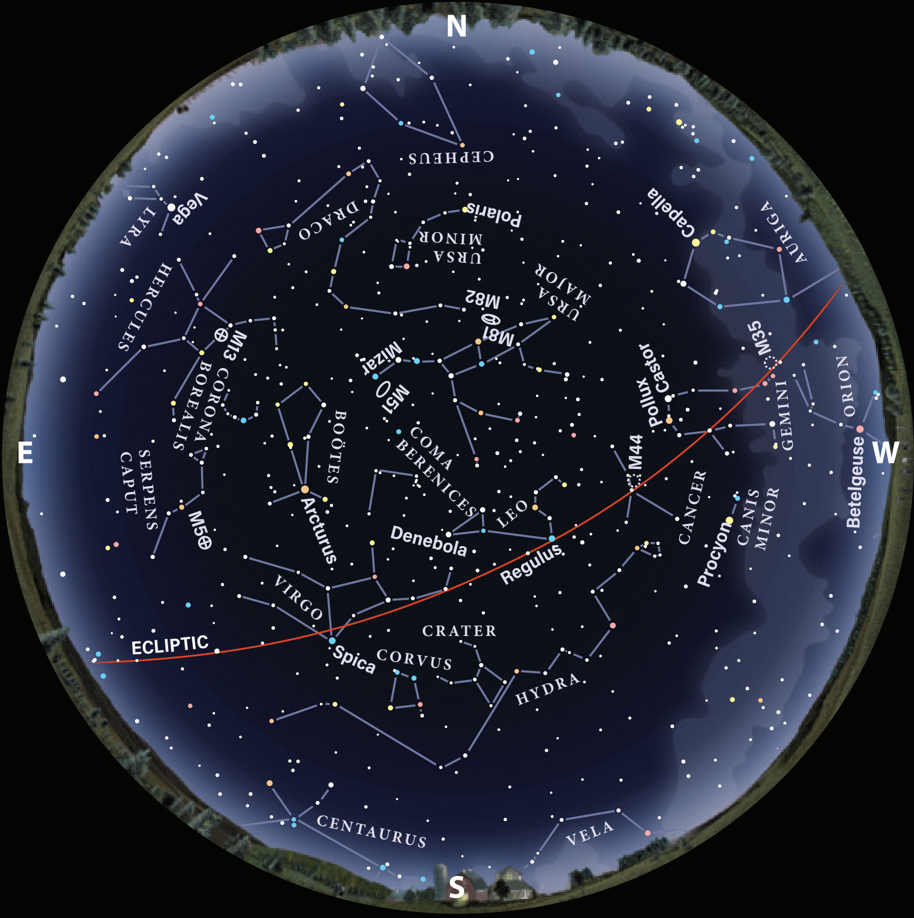
Deep-sky highlights

The Beehive Cluster (M44) was used to forecast weather in antiquity. It is a naked-eye object under a clear, dark sky, but it disappears under less optimal conditions.

M5, a conspicuous globular cluster, lies between the figures of Virgo the Maiden and Serpens Caput the Serpent's Head.

The Whirlpool Galaxy (M51) is a vast spiral about 30 million light-years away.

M81 and **M82** in Ursa Major form a pair of galaxies that you can spot through a telescope at low power.


N
E
W
S
CEPHEUS
Vega
LYRA
DRACO
Polaris
URSA MINOR
Capella
AURIGA
HERCULES
M82
M81
URSA MAJOR
M3
CORONA BOREALIS
Mizar
M51
Castor
Pollux
M35
GEMINI
ORION
SERPENS CAPUT
BOÖTES
COMA BERENICES
M44
CANCER
CANIS MINOR
Betelgeuse
M5
Arcturus
Denebola
LEO
Regulus
Procyon
VIRGO
ECLIPTIC
CRATER
Spica
CORVUS
HYDRA
CENTAURUS
VELA

Jan. 10	Jupiter is at opposition
Feb. 17	Annular solar eclipse
Feb. 19	Mercury is at greatest eastern elongation
March 3	Total lunar eclipse
April 22	Lyrid meteor shower peaks
May 6	Eta Aquariid meteor shower peaks
June 9	Venus passes 1.6° north of Jupiter
June 15	Mercury is at greatest eastern elongation
July 27	Pluto is at opposition
Aug. 2	Mercury is at greatest western elongation
Aug. 12	Total solar eclipse

STAR MAPS BY *ASTRONOMY*: ROEN KELLY

Aug. 12
Perseid meteor shower peaks

Aug. 15
Venus is at greatest eastern elongation

Aug. 28
Partial lunar eclipse

Sept. 25
Neptune is at opposition

Oct. 4
Saturn is at opposition

Oct. 13
Asteroid Vesta is at opposition

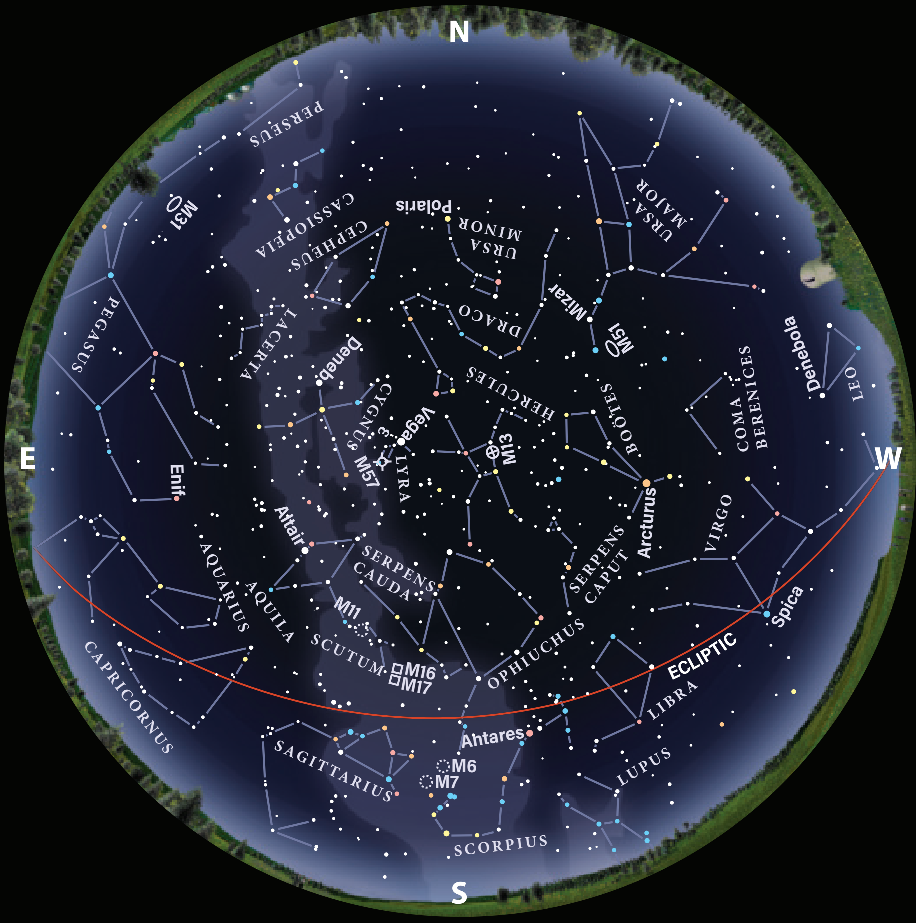
Oct. 21
Orionid meteor shower peaks

Nov. 17
Leonid meteor shower peaks

Nov. 20
Mercury is at greatest western elongation

Nov. 25
Uranus is at opposition

Dec. 14
Geminid meteor shower peaks


N
S
E
W
PERSEUS
M31
CASSIOPEIA
CEPHEUS
Polaris
URSA MINOR
URSA MAJOR
PEGASUS
LACERTA
Deneb
DRACO
Mizar
M51
CYGNUS
Vega
LYRA
M57
M13
HERCULES
BOÖTES
COMA BERENICES
Denebola
LEO
Enif
Altair
SERPENS CAUDA
SERPENS CAPUT
Arcturus
VIRGO
Spica
AQUARIUS
AQUILA
M11
SCUTUM
M16
M17
OPHIUCHUS
ECLIPTIC
LIBRA
CAPRICORNUS
Ahtares
SAGITTARIUS
M6
M7
LUPUS
SCORPIUS

SUMMER

The sky

High in the sky, the three bright stars known as the Summer Triangle are easy to spot. These luminaries — Vega in Lyra, Deneb in Cygnus, and Altair in Aquila — lie near the starry path of the Milky Way. Following the Milky Way south from Aquila, you'll find the center of our galaxy in the constellation Sagittarius the Archer. Here lie countless star clusters and glowing gas clouds. Just west of Sagittarius is Scorpius the Scorpion, which contains the red supergiant star Antares as well as M6 and M7, two brilliant clusters that look marvelous at low power.

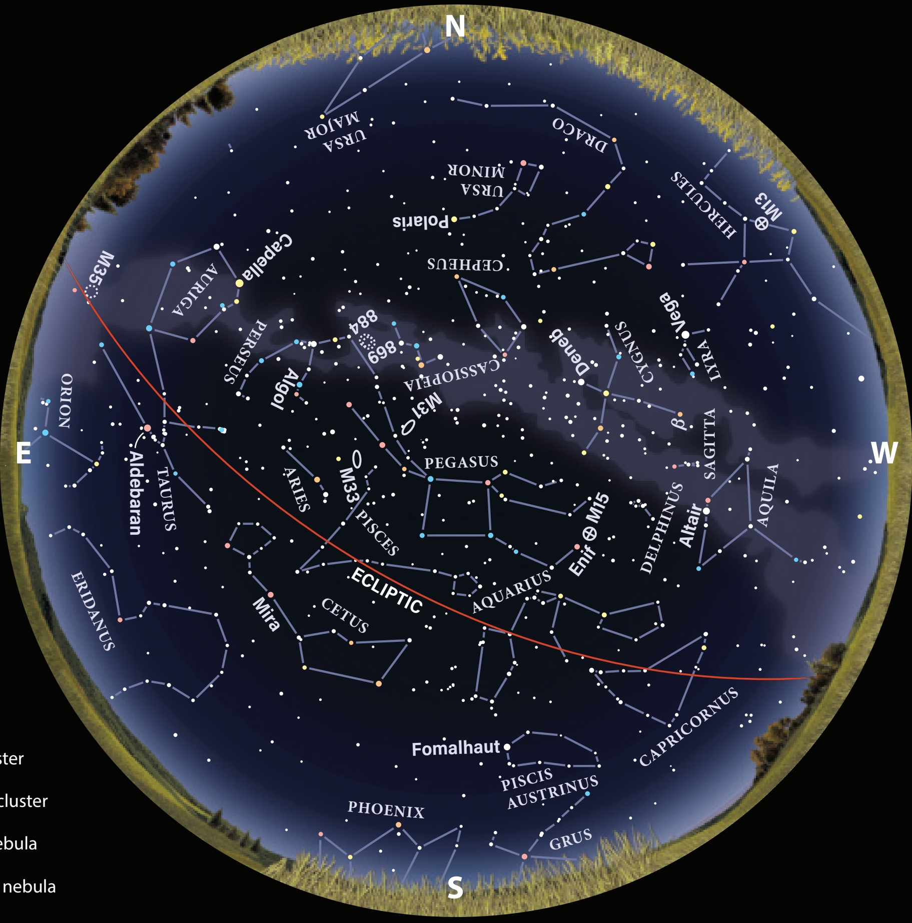
Deep-sky highlights

The Hercules Cluster (M13) contains nearly a million stars and is the finest globular cluster in the northern sky.

The Ring Nebula (M57) looks like a puff of smoke through a medium-sized telescope.

The Omega Nebula (M17) looks like the Greek letter of its name (Ω) through a telescope at low power. This object also is called the Swan Nebula.

The Wild Duck Cluster (M11) is a glorious open star cluster. On a moonless night, a small scope will show you some 50 stars.


N
URSA MAJOR
DRACO
URSA MINOR
Polaris
HERCULES
M13
CEPHEUS
Capella
AURIGA
M35
PERSEUS
884
869
CASSIOPEIA
Deneb
CYGNUS
Vega
LYRA
Algol
M31
ORION
E
W
β
SAGITTA
PEGASUS
ARIES
M33
Aldebaran
TAURUS
PISCES
M15
Enif
DELPHINUS
Altair
AQUILA
ERIDANUS
Mira
CETUS
ECLIPTIC
AQUARIUS
CAPRICORNUS
Fomalhaut
PISCIS AUSTRINUS
PHOENIX
GRUS
S

AUTUMN

The sky

The Big Dipper swings low this season, and from parts of the southern U.S., it even sets. With the coming of cooler nights, Pegasus the Winged Horse rides high in the sky as the rich summer Milky Way descends in the west. Fomalhaut, a solitary bright star, lies low in the south. The magnificent Andromeda Galaxy reaches its peak nearly overhead on autumn evenings, as does the famous Double Cluster. Both of these objects appear as fuzzy patches to the naked eye under a dark sky.

Deep-sky highlights

The Andromeda Galaxy (M31) is the brightest naked-eye object outside our galaxy visible in the northern sky.

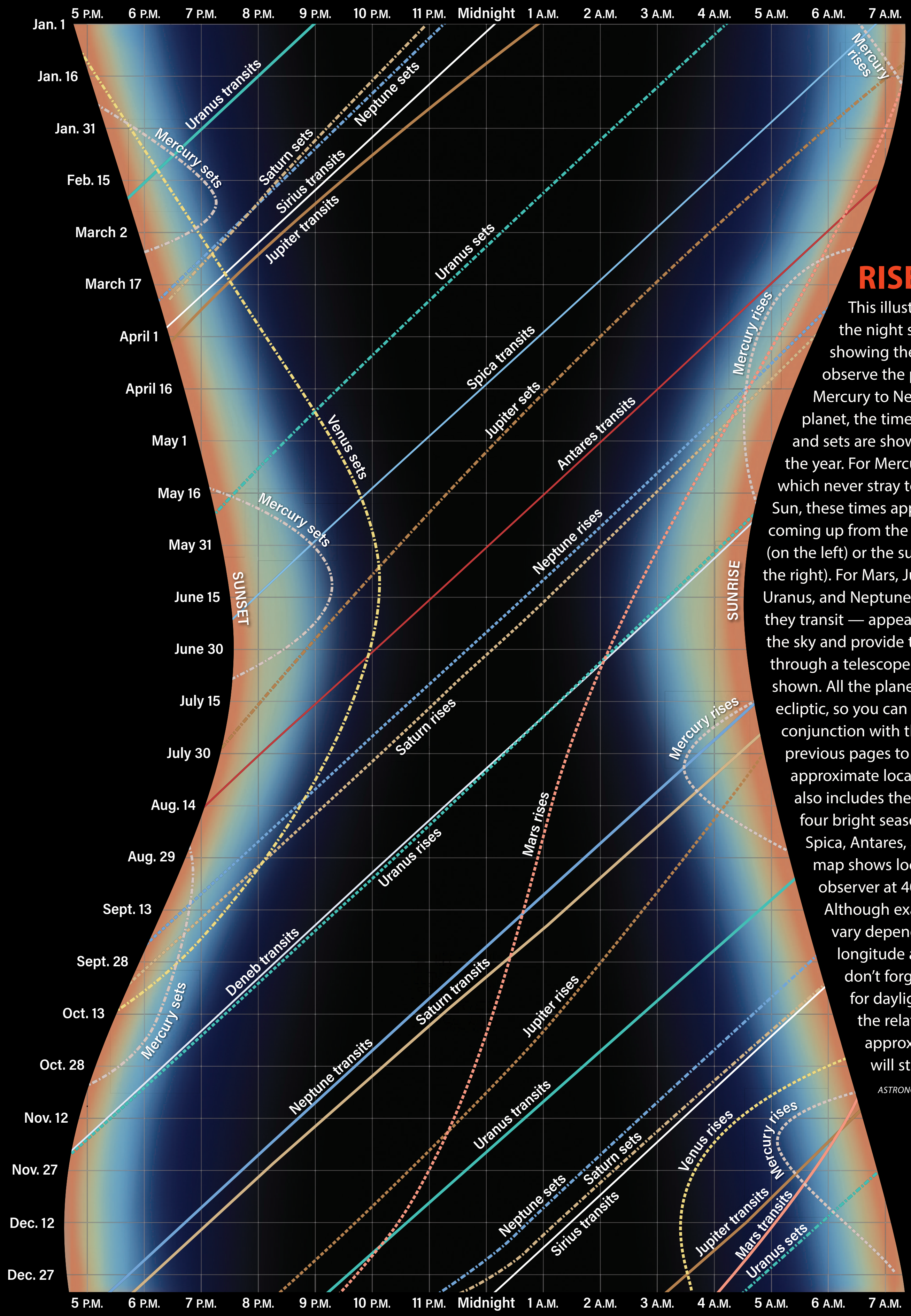
The Double Cluster (NGC 869 and NGC 884) in Perseus consists of twin open star clusters. It's a great sight through binoculars.

M15 in Pegasus is a globular cluster containing hundreds of thousands of stars, many of which can be glimpsed through a medium-sized telescope.

Albireo (Beta [β] Cygni), the most beautiful double star in the sky, is made up of suns colored sapphire and gold.

◌ Open cluster
⊕ Globular cluster
☐ Diffuse nebula
⌖ Planetary nebula
⬭ Galaxy

Astronomy magazine



RISE & SET

This illustration presents the night sky for 2026, showing the best times to observe the planets from Mercury to Neptune. For each planet, the times when it rises and sets are shown throughout the year. For Mercury and Venus, which never stray too far from the Sun, these times appear as loops coming up from the sunset horizon (on the left) or the sunrise horizon (on the right). For Mars, Jupiter, Saturn, Uranus, and Neptune, the times when they transit — appear highest in the sky and provide the best view through a telescope — also are shown. All the planets lie near the ecliptic, so you can use this chart in conjunction with the maps on the previous pages to find a planet's approximate location. The chart also includes the transit times of four bright seasonal stars: Sirius, Spica, Antares, and Deneb. This map shows local times for an observer at 40° north latitude. Although exact times will vary depending on your longitude and latitude (and don't forget to add an hour for daylight saving time), the relative times and approximate positions will stay the same.

ASTRONOMY: ROEN KELLY

SOUTHERN SKY

BY MARTIN GEORGE

February 2026

A pair of pretty gas giants

The solar system's two largest planets adorn the evening sky this month, while the smaller inner planets linger near the Sun and remain mostly out of sight.

You'll want to make **Saturn** your first target as darkness descends. The ringed planet shines at magnitude 1.0 and appears low in the west among the faint background stars of Pisces the Fish. Although Saturn stands 46° east of the Sun in early February, the ecliptic makes a shallow angle to the western horizon from mid-southern latitudes at sunset this time of year, so the planet hangs low in our sky.

The best views through a telescope come during fleeting moments of steady seeing. In mid-February, Saturn's disk measures 16" across while the rings span 37" and tilt 3° to our line of sight. Also look for the planet's largest satellite, 8th-magnitude Titan, which completes an orbit of the giant world every 16 days.

Saturn serves as a convenient guide to the outermost major planet around mid-month. On the 16th, the ringed world passes 0.9° south (upper left) of **Neptune**. You should be able to spot the 8th-magnitude planet through a small scope.

Magnitude –2.5 **Jupiter** stands as the brightest object in February's evening sky. The giant planet appears in the northeast as twilight fades to darkness. It moves slowly westward against the backdrop of central Gemini, some 10° above the Twins' brightest stars, Castor and Pollux.

A telescope resolves fine detail in the gas giant's atmospheric bands. The best views come when it climbs highest in the north during the late evening hours. Look for two parallel dark belts, one on either side of a brighter zone that coincides with Jupiter's equator, which spans 44" in mid-February. The planet's four bright moons should also stand out on any clear evening.

Earth's three closest planetary neighbors fare far worse than their more distant siblings. **Venus** crawls slowly away from the Sun into the evening sky while **Mars** does the same in the morning sky. Yet neither achieves a significant elongation by month's end. Venus then stands 13° from the Sun and Mars is only 12° from our star.

Mercury reaches greatest elongation Feb. 19, when it lies 18° east of the Sun but appears just 3° above the western horizon 30 minutes after sunset from mid-southern latitudes. It will be a bit higher if you live closer to the equator.

An annular solar eclipse occurs Feb. 17, though most observers of the event will be penguins because the path makes landfall only in Antarctica. The center line passes about 500 kilometers east of Australia's Davis Station. Those hardy souls in Davis can see a partial eclipse. Maximum occurs at 12h04m UT, when the Moon obscures 95 percent of the Sun's diameter. Residents in southeastern Africa and the southern tip of South America will witness a lesser partial eclipse. Wherever you are, be sure to use a safe solar filter to view the event.

The starry sky

The wonderful Orion the Hunter ranks among the showpiece star patterns in the entire sky. It contains several prominent stars as well as one of the finest star-forming regions — the great Orion Nebula (M42) — to explore with a small telescope. The constellation climbs high in the north in February's early evening sky.

Orion's two brightest stars, blue-white Rigel and reddish Betelgeuse, vie for attention because of their brilliance and contrasting colors. But this month I want to highlight the Hunter's other two corner stars: Bellatrix and Saiph.

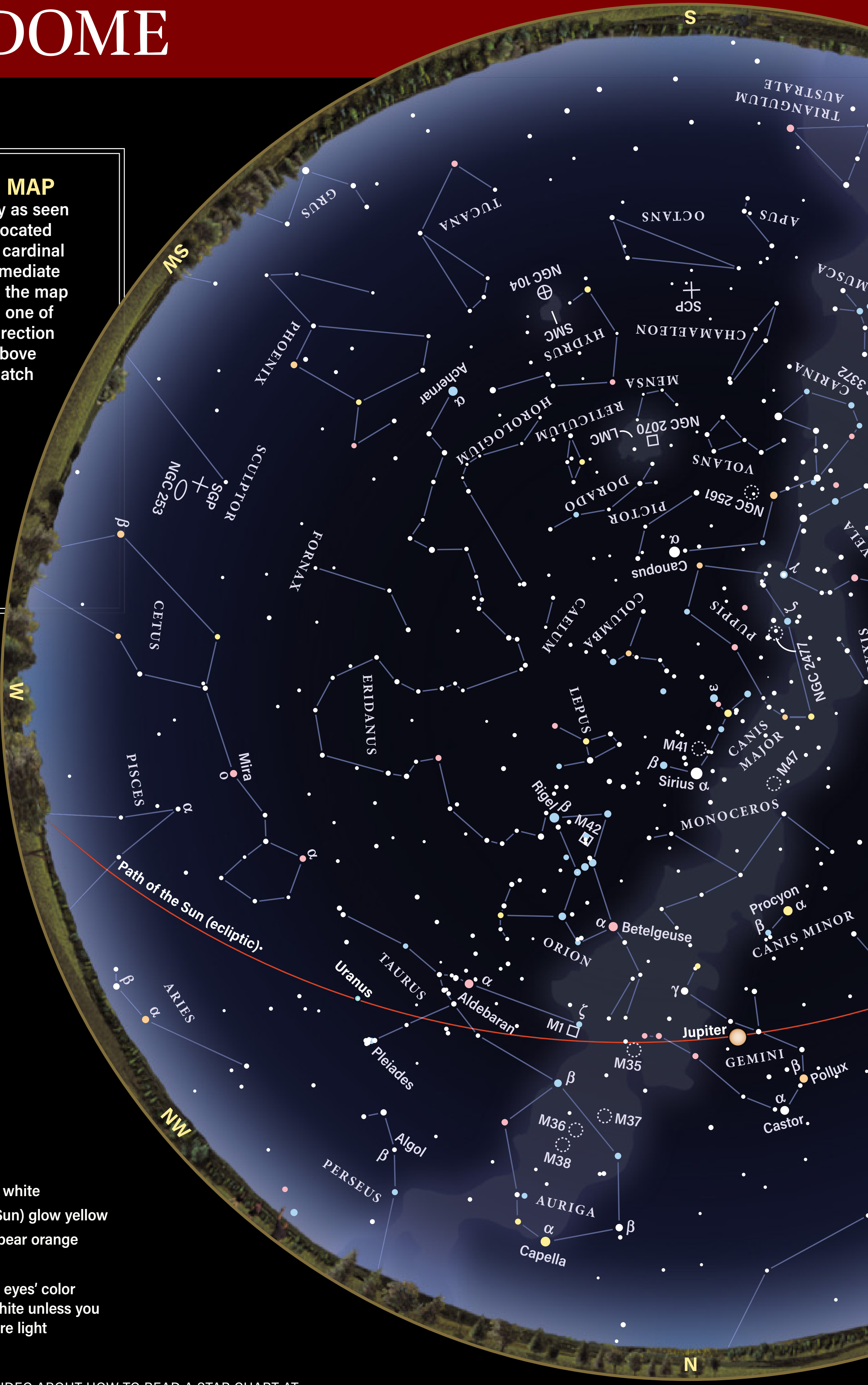
From our point of view, Bellatrix (Gamma [γ] Orionis) lies at the lower left of the main group of stars and marks one of the giant's shoulders. It has a mass about 8.5 times that of the Sun and shows a spectral type of B2. Compare its blue-white color with ruddy Betelgeuse, which lies 7.5° to the east (right).

Although Bellatrix appears to be a single star, some researchers suspect it has a stellar companion. Gamma glows at magnitude 1.6, and for a long time astronomers thought it shone steadily. That made it a convenient "standard star" for UBV photometry (the measurement of stellar brightness in the three spectral bands of ultraviolet, blue, and visible light). Indeed, it was on that list when I put together photometric equipment for Tasmania's largest telescope in the 1970s. However, scientists have since found that it varies slightly in brightness between magnitudes 1.59 and 1.64.

If you jump diagonally across Orion to the upper right, you'll pass by the three conspicuous stars of Orion's Belt and then come to magnitude 2.1 Saiph (Kappa [κ] Ori), which marks one of the Hunter's legs. Saiph is the southernmost of Orion's bright stars and stands only 1° north of the constellation's border with Lepus the Hare.

Although Kappa appears half a magnitude dimmer than Bellatrix, that's a little misleading. If you compare the two star's intrinsic brightnesses, Saiph is the real standout. Astronomers use absolute magnitude, the apparent brightness a star would have if it were 10 parsecs (32.6 light-years) away from us, to measure true luminosity. On this scale, Bellatrix shines at magnitude –2.8 while Saiph, a blue supergiant with about 15 times the Sun's mass, gleams at magnitude –6.1, or some 21 times brighter. If Saiph were only 10 parsecs away, it would be obvious in broad daylight and outshine Venus by at least 1.5 magnitudes.

STAR DOME


S
SW
W
NW
N
TRIANGULUM AUSTRALE
APUS
OCTANS
TUCANA
GRUS
MUSCA
SCP
NGC 104
SMC
HYDRUS
CHAMAELEON
PHOENIX
Achernar
α
MENSA
CARINA
3372
HOROLOGIUM
RETICULUM
LMC
NGC 2070
VOLANS
SGP
NGC 253
SCULPTOR
DORADO
PICTOR
NGC 2561
VELA
β
FORNAX
Canopus
α
λ
CETUS
CAELUM
COLUMBA
PUPPIS
ζ
NGC 2477
ERIDANUS
LEPUS
ε
Mira
o
M41
CANIS MAJOR
β
Sirius
α
M47
PISCES
α
Rigel
β
M42
MONOCEROS
α
Path of the Sun (ecliptic)
Procyon
α
β
CANIS MINOR
ORION
α
Betelgeuse
Uranus
TAURUS
α
Aldebaran
M1
ζ
γ
β
ARIES
α
Jupiter
Pleiades
M35
GEMINI
β
Pollux
α
Castor
β
M36
M37
Algol
β
M38
PERSEUS
AURIGA
α
Capella
β

HOW TO USE THIS MAP

This map portrays the sky as seen near 30° south latitude. Located inside the border are the cardinal directions and their intermediate points. To find stars, hold the map overhead and orient it so one of the labels matches the direction you're facing. The stars above the map's horizon now match what's in the sky.

The all-sky map shows how the sky looks at:

10 P.M. February 1
9 P.M. February 15
8 P.M. February 28

Planets are shown at midmonth

MAP SYMBOLS

- ◌ Open cluster
- ⊕ Globular cluster
- □ Diffuse nebula
- ⌖ Planetary nebula
- ⬭ Galaxy

STAR MAGNITUDES

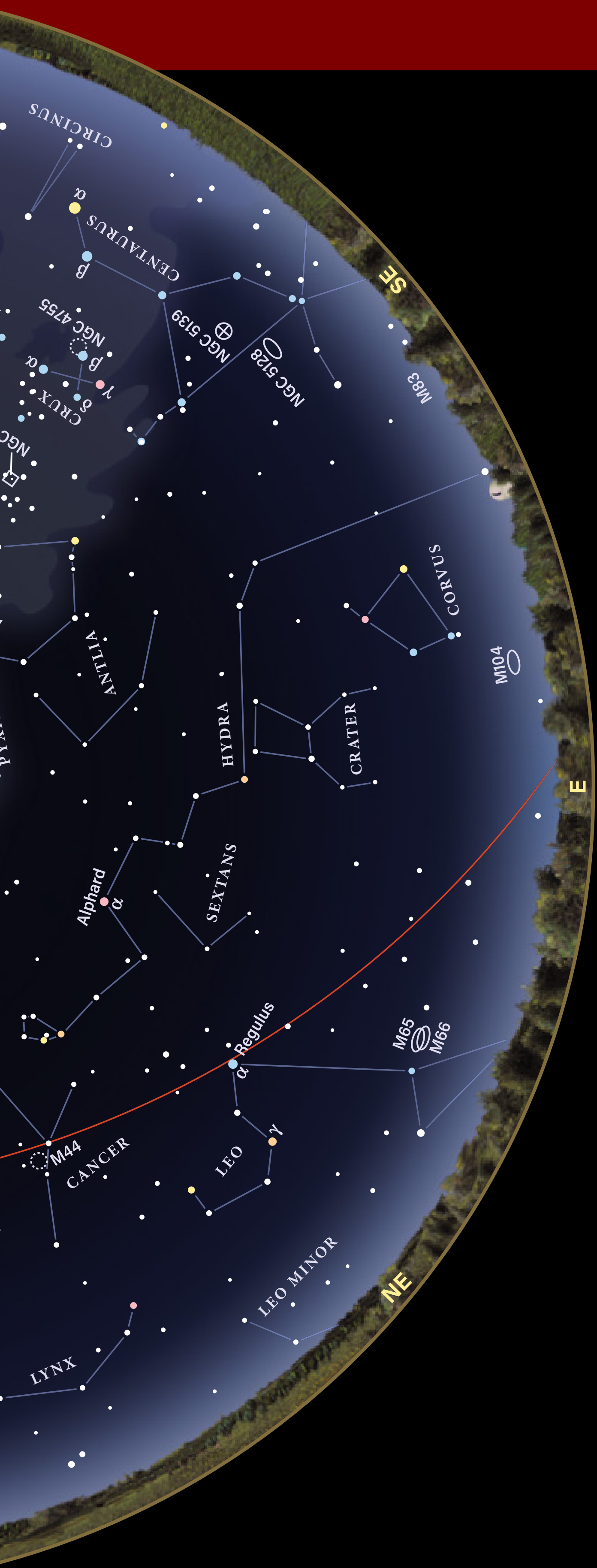
●	Sirius		
●	0.0	•	3.0
●	1.0	•	4.0
•	2.0	·	5.0

STAR COLORS

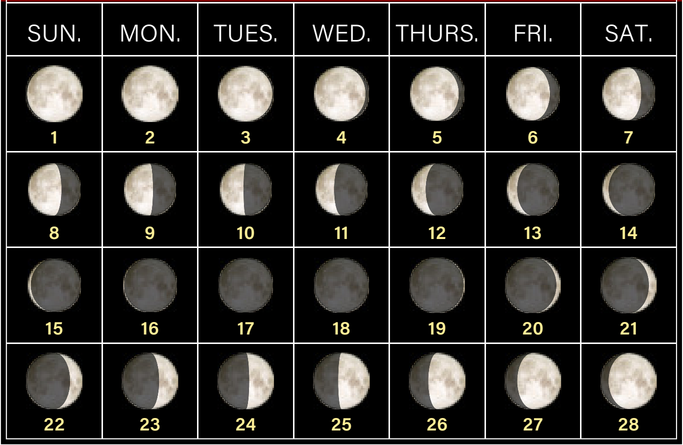
A star's color depends on its surface temperature.

- 🟦 The hottest stars shine blue
- ⬜ Slightly cooler stars appear white
- 🟨 Intermediate stars (like the Sun) glow yellow
- 🟧 Lower-temperature stars appear orange
- 🟥 The coolest stars glow red
- ⬜ Fainter stars can't excite our eyes' color receptors, so they appear white unless you use optical aid to gather more light

BEGINNERS: WATCH A VIDEO ABOUT HOW TO READ A STAR CHART AT
www.Astronomy.com/starchart.


CIRCINUS
α
β
CENTAURUS
SE
NGC 4755
NGC 5139
NGC 5128
α
β
γ
δ
CRUX
NGC
M83
CORVUS
M104
ANTLIA
HYDRA
CRATER
E
Alphard
α
SEXTANS
M65
M66
Regulus
α
γ
LEO
M44
CANCER
NE
LEO MINOR
LYNX

FEBRUARY 2026



SUN.	MON.	TUES.	WED.	THURS.	FRI.	SAT.
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28

ILLUSTRATIONS BY ASTRONOMY: ROEN KELLY

Note: Moon phases in the calendar vary in size due to the distance from Earth and are shown at 0h Universal Time.

CALENDAR OF EVENTS

1 ○ Full Moon occurs at 22h09m UT

3 The Moon passes 0.4° north of Regulus, 3h UT

4 Uranus is stationary, 5h UT

9 ◑ Last Quarter Moon occurs at 12h43m UT

10 The Moon is at apogee (404,576 kilometers from Earth), 16h52m UT

11 The Moon passes 0.7° south of Antares, 4h UT

15 The Moon passes 0.9° north of Pluto, 15h UT

16 Saturn passes 0.9° south of Neptune, 4h UT

17 ● New Moon occurs at 12h01m UT; annular solar eclipse

18 The Moon passes 1.7° north of Venus, 9h UT

The Moon passes 0.1° south of Mercury, 23h UT

19 Mercury is at greatest eastern elongation (18°), 18h UT

20 The Moon passes 4° north of Neptune, 0h UT

The Moon passes 5° north of Saturn, 0h UT

24 The Moon passes 6° north of Uranus, 1h UT

◐ First Quarter Moon occurs at 12h28m UT

The Moon is at perigee (370,135 kilometers from Earth), 23h14m UT

25 Mercury is stationary, 17h UT

26 Mercury passes 5° north of Venus, 23h UT

27 The Moon passes 4° north of Jupiter, 6h UT

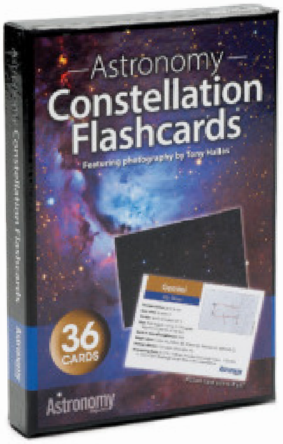
Asteroid Iris is at opposition, 18h UT

EXPLORE THE UNIVERSE

The Carina Nebula's Mystic Mountain
Astronomy
500 PIECE PUZZLE

Visit TheSpaceStore.com today for high-quality astronomy products, many curated by the *Astronomy* magazine team.

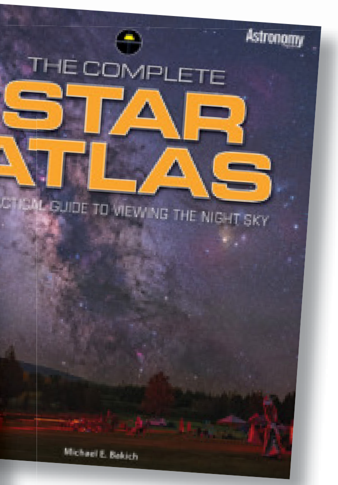
- Custom-produced globes, as well as others from top manufacturers.
- Books and DVDs covering solar eclipses, observing guides, the cosmos and more.
- Magazines bringing you the latest astronomical discoveries and events.
- Collectible items to commemorate historic launches.
- Toys and games-have fun learning about astronomy!
- And much more!


Astronomy
Constellation Flashcards
36 CARDS
Astronomy

GALILEOSCOPE
50-mm Refractor Telescope Kit

The Milky Way from above
Astronomy

Astronomy
SPECIAL ISSUE
COSMOS
ORIGIN AND FATE OF THE UNIVERSE
500+ AMAZING FACTS you need to know about
GALAXIES


Astronomy
THE COMPLETE STAR ATLAS
PRACTICAL GUIDE TO VIEWING THE NIGHT SKY
Michael E. Bakich

space® STORE

Shop now at:
TheSpaceStore.com
Sales tax where applicable.

P39082